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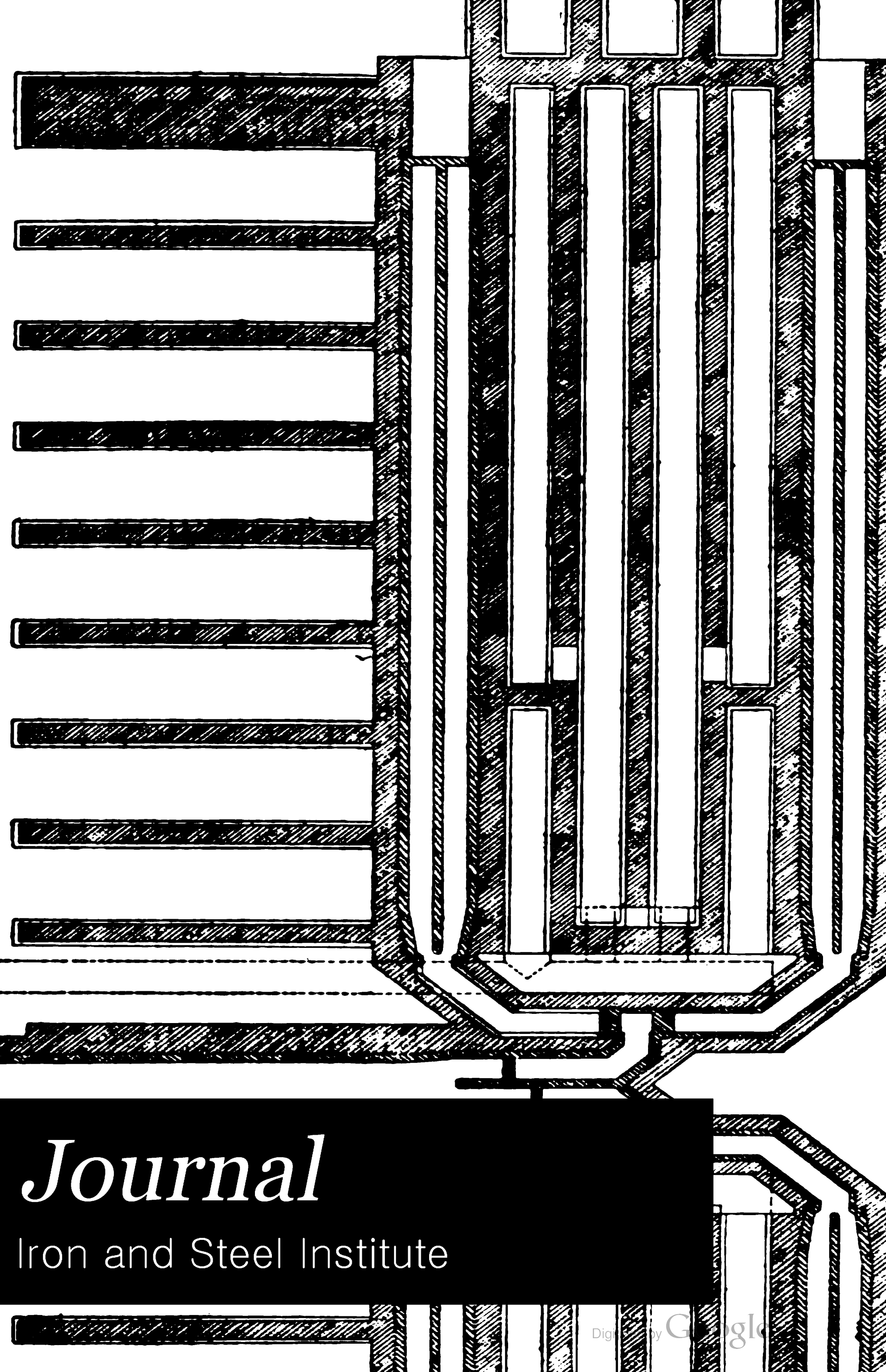

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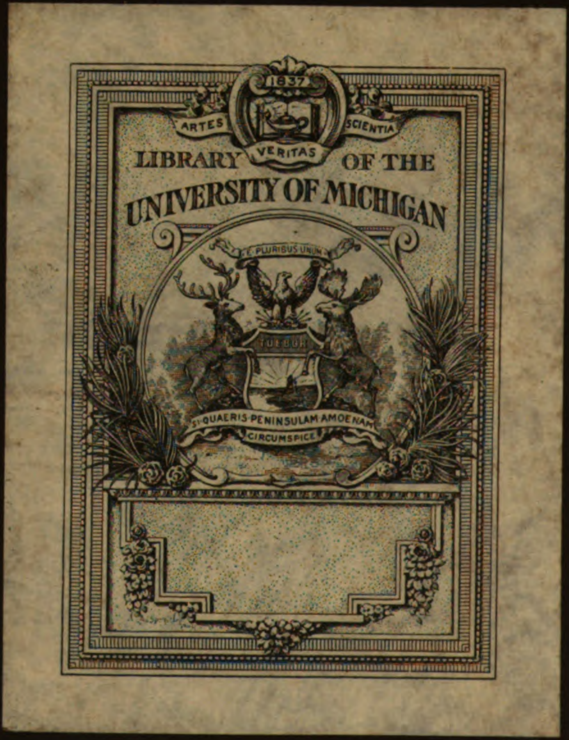

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PROCEEDINGS

OF THE

IRON AND STEEL INSTITUTE.

NEW YORK MEETING, 1890.

WEDNESDAY, OCTOBER 1ST.

THE PROCEEDINGS of the INSTITUTE were opened this forenoon at Chickering Hall, New York—Sir **JAMES KITSON**, Bart., President of the Institute, occupying the chair.

Mr. **ANDREW CARNEGIE**, Chairman of the American Reception Committee, said: Welcome! thrice welcome to our guests from the shores of the old land to the shores of the new. Speaking as a representative, and on behalf of the various kindred societies of the United States, he had the pleasure of welcoming them as guests. To the members of the Iron and Steel Institute the members of the Verein Deutscher Eisenhüttenleute, and the gentlemen from the sister Republic of France, they extended both hands in cordial greeting and welcome, under the sacred name of guests. Many of the members of their own societies had been privileged on more than one occasion to acknowledge their most generous hospitality. Wherever their members had gone, they had been hailed, not only as brother-workers, not only as friends, but as kinsmen, and the claim of kinship which they had been so proud to make had everywhere been most cordially acknowledged. The debt which the new land owed to the old land baffled description. In the domains of iron, coal, and steel they had nothing whatever to show their visitors but the development of ideas from the old country. Cort and Neilson, Nasmyth, Bessemer, Siemens, Thomas and Gilchrist, and others were the inventors of the processes which they were now to see in force in the United States, and it had only been by these inventions that the amazing development of the country had been rendered possible. In mechanical and in civil engineering processes they would see something which might lead them to believe that the contribution which the new land had made to recent progress in these branches had not been inconsiderable. In the matter of pneumatic tubes, and in bridge construction, and, most important of all, in the building, management, and operation of railways, especially the city railways, they hoped their guests would see much that would cause them to consider. One of their hosts was the Electrical Society. In electricity the new land had a fair start with Europe; the discoveries there had all been of a date so recent. Their electrical friends, with Mr. Edison at their head, were most anxious to show their latest achievements. Indeed, the whole continent was open for their inspection.

The Committee which he represented had been overwhelmed with invitations. While they gratified one, they would give offence to twenty, by not being able to bring their guests to them; and if there was any gentleman who wished to investigate a subject not upon the official list, he was sure he had only to intimate the desire to have his wish fully gratified. No manufacturer, no scientist, but had opened his doors, and called upon them to investigate, and if they did not see everything they wanted to see, they must ask for fuller information. They must not be delicate, or hesitate to go to the root of the matter; for, after all, the United States had taken everything that was good from their guests, who, indeed, need have no hesitation in taking all that they could get from America. The scientist of to-day pursued his calling anxious for the discovery of truth, not concerned as to who should reap the first or most immediate advantage. In like manner, manufactures and commerce were conducted on a scale so vast that there was no room any longer for petty antagonism. The gain of one was not the loss of another. And here they had followed the example of an Institution that published its best results, most anxious to help on the general progress of the world in this branch of business. Their own societies in America were animated by a like spirit, and they followed the example of the old Iron and Steel Institute. They might take everything they could from them, and the more advantageous it was to them, the better their hosts would like it; for it was the great desire of their hosts that this visit might be of practical and lasting benefit to all parties concerned.

The age was distinguished by one feature; it was an age of "firsts"—so many things were now done for the first time. They celebrated a "first" that morning, for that was the first time that the Iron and Steel Institute had crossed the Atlantic to hold its annual meeting as the guest of its kindred societies. He hoped it would not be the last. One hundred years from then, perhaps, they would celebrate the centennial of that meeting. How petty their respective lands, their inventions, discoveries, and manufactures now, compared with what they would be then. The United States would probably then have more than four hundred millions of citizens. Perhaps those who occupied the proud position which their guests occupied that day might be able to rise and tell of a three days' pleasant excursion across the Atlantic, and dwell upon the merits of electricity as the motive power. But however petty they might regard the achievements of to-day, there was one record which could never be blotted out or obscured—namely, that for the first time this generation had inaugurated that meeting upon the shores of the Republic, and it would be said that in doing this their predecessors had done well.

He had said that their hope was that this visit might be of great material benefit to the visitors. He should but poorly perform his office if he did not say that there was another wish still dearer to their hearts than that: they trusted that from that visit many new friendships would be formed, and many old ones cemented. They hoped that the visitors from the old land would come to know their guests better, and that they of the new land would know *them* better. That was a peaceful Republic. No man there would echo that sentiment more cordially than his friend General Sherman, whom he saw before him. Yes, in the presence of General Sherman he said that was a peaceful, because an industrial, Republic. They hoped that the principles of peace and goodwill would be promoted by the visit; that their guests would learn to think of their kindred kindly, cordially, and frankly; and that the new land would learn to reverence still more the land of their fathers, to which they were so deeply attached. His last words were his first words: welcome, thrice welcome to the shores of the Republic; and, varying the quotation slightly, he might say, if all their services were twice done and then done doubly, it were a poor and single business to contend against the benefits, broad and deep, which the Iron and Steel Institute had conferred upon that young land of America.

THE PRESIDENT'S ADDRESS.

The **President** said: Gentlemen of the iron, steel, and engineering industries of the United States—It was very pleasant and agreeable to hear that word "Welcome!" spoken in the mother-tongue. It had been his duty to answer messages of welcome in other lands. He remembered to have descended at the station of Buda-Pesth, and to have been addressed in the Hungarian language. It was his lot also to respond last year, as President, to the words of welcome which were offered to them by their French hosts; but it was doubly pleasant and agreeable to respond there in the United States to that "welcome," spoken in the mother-tongue, and offered to them in such eloquent terms by Mr. Carnegie. Mr. Carnegie had pointed out to them that the circumstances under which they met there were very remarkable. The invitation which they had had the honour to receive, and which they had acknowledged by their presence in New York, had first been offered to them long ago, and the possibility of accepting it had long been discussed. He believed that as far back as 1873, when they met at Liége, under the presidency of Sir Lowthian Bell, their own secretary, Dr. Raymond (who still, he was glad to see, continued his arduous scientific labours, to the great advantage of the iron and steel trades), offered them an invitation on behalf of the American Mining Institute. Well, the perils of the voyage, the difficulties of transport, and the length of time involved, made them hesitate somewhat to accept the invitation, because they were afraid that it might not be possible, owing to those difficulties, to present before them a full and true representation of the great industries in which they were engaged. For example, they greatly desired that Sir Henry Bessemer should have been present, but the trials of the sea-passage, and his age, had prevented him from coming. Sir Henry, however, desired him to say that it was with much reluctance that he had given up all hope of being able to undertake the voyage. Mr. Carnegie had said that that was a day of "firsts," which, indeed, it truly was. They were met in the year when the United States had become the first producer of iron in the world. For the first time the production of pig iron in the United States had exceeded, in the year past, the production of Great Britain, and he felt from what they saw, and from what they were to see, that the United States had attained in that respect a pre-eminence which the old country might never be able to recover. However, as Mr. Carnegie said, two of a trade could agree, and he himself always considered that when his neighbour was prosperous, when his competitor was full of work, the conditions of commerce must also favour himself; and if the United States was producing, and, what was equally important, also consuming such an enormous quantity of material, they might rest assured that its superabundant prosperity could not fail to have a beneficial effect upon other nations.

That was, indeed, a day of firsts, because they had had an address of welcome offered to them by the first iron producer of the world. He believed he was well informed in stating that Mr. Carnegie was the largest producer of iron and steel in the world. That was a day of firsts, because on all hands they heard of the stupendous preparations which were being made for their reception, and they knew that the eloquent words which Mr. Carnegie had spoken did not convey any full measure of the wondrous welcome which they were to receive throughout the United States. It was very agreeable, and it gave food for reflection, to hear their host lay so much stress upon the hereditary principle. Mr. Carnegie very rightly made a great point of the hereditary principle in the iron trade; and they might take to themselves the credit of representing, if not in their own persons, yet in a glorious past, the iron trade of the world. He thought he might fairly claim for them that the members of the British iron trade had been everywhere the pioneers of invention and of improvement in the iron and steel trades; and therefore, although they might not be a complete deputation of the great interests which they represented, yet, looking to the past, they felt justified in venturing thankfully to accept the gracious welcome which had been offered to them.

He had prepared some further remarks for these opening proceedings, and with their permission would now offer them.

Mr. Cobden, in the year 1853, made a speech upon education, in which he said: "When I came through Manchester the other day, I found many of the most influential manufacturing capitalists talking very gravely upon a report which had reached them, from a gentleman who was selected by the Government to go out to America to make a report upon 'the Great Exhibition in New York. That gentleman was one of the most eminent of the mechanicians of Manchester, renowned for the quality of his productions, and known in the scientific world. He reports that he has found in America a degree of intelligence among the manufacturing operatives, and a state of things in the mechanical arts, which have convinced him that, if we are to hold our own, if we are not to fall back in the rear of the race of nations, we must educate our people, so as to put them on a level with the more educated artisans of the United States." And previously to this, Mr. Cobden had written, as early as 1835, "If knowledge be power, and if education gives knowledge, then must the Americans inevitably become the most powerful people in the world."

We now know that the predictions and conclusions of this great Englishman have been realised and surpassed. The future of the United States has gone beyond the possibilities which his observations and his reasonings so clearly pictured.

The remarkable men who framed the system under which the expansion of commerce has been so great, were wise beyond measure in their care and liberality in the work of education.

We meet here on the invitation of the members of the American Institute of Mining Engineers, the American Iron and Steel Association, with whom are also associated the Societies of Mechanical and Civil Engineers, representing fully the metallurgical interests of the United States. This invitation was repeated to us in eloquent terms by the Hon. A. Hewitt, at our meeting in London, in May of this year, and further supplemented personally by a representative of Mr. Bardeleben and his associates, who conveyed to the Institute an invitation to visit the principal ore and coal sections of Alabama. We come to examine the industrial condition, and to inspect as fully as our time will permit, the natural advantages and the manufacturing capabilities of the iron and steel trade of the United States. We come here simply as the guests of the iron and steel trades of the United States, but the welcome we have received, and the remarkable reception which has been accorded to us since we landed on these shores, gives us ground for believing that we are also welcomed by great numbers of the people of the United States.

The necessity for general, broader, and advanced education has of late years been very generally acknowledged by the English nation. I cannot here venture to give you any account of the means and methods by which wider and more advanced education has been given and secured to the English people. But the warning I have here referred to was not disregarded by those concerned in the welfare and the progress of the industries of the United Kingdom of Great Britain and Ireland.

The national system of elementary education, obtained through the advocacy of many enlightened men and the national will, and definitely carried into effect by the legislation of that eminent statesman, the late W. E. Forster, was followed, supplemented, and sustained as to higher education by the munificence of many voluntary associations and private individuals, amongst whom we may proudly claim, as workers in metals, Josiah Mason, the founder of the Science College in Birmingham, and Sir Joseph Whitworth, a member of this Institute, as having done much to aid in placing us on an equal footing with this and other nations.

Following the establishment of many scientific institutions, which are among the distinguishing characteristics of the times in which we live, we have had a great creation of scientific societies devoted to special subjects. Amongst them is the Iron and Steel Institute—whose autumn session I am now privileged to open in New York—which was founded in the year 1869. Through its agency many inventions, new machinery, new methods and processes, which would otherwise have been but tentatively and tardily adopted, have been appreciated and acquired promptly, and made rapidly and advantageously the property of the whole world; and what has been, too, of almost equal practical service, errors, mistakes, and misleading methods have been discussed, exploded, and discarded.

Our first President was His Grace the Duke of Devonshire, whose acceptance of this position conferred a prestige on the Institute, and on the iron and steel trades, by securing the recognition of a true representative of social rank, vast metallurgical interests, and high intellectual attainments. This recognition of the great importance of the aims of our Institute, and the unbounded possibility of the value of its inquiries, discussions, and communications, which were to be undertaken for the advancement of the iron and steel trades, was at that moment most valuable. He was succeeded by Sir Henry Bessemer, whose brilliant discovery of a process for the production of steel, with which his name will for ever be associated, has revolutionised the trade, and led to vast industrial developments throughout the world. Next came Sir Lowthian Bell, described, and justly so, by your Professor Howe, as "*Magister magnus in ignibus*," whose interest in our work and proceedings has been maintained with unflagging zeal for one-and-twenty years; and whose scholarly attainments and scientific and practical knowledge have been of infinite service to this Institute.

These three first Presidents happily still remain to us. Sir William Siemens has passed away, but his contributions to the Institute, his scientific achievements, his discoveries and his development of the regenerative furnace, the process of open-hearth steel-making, and the production of a description of mild steel so generally applied in commerce, are amongst the inestimable advantages conferred on the world by the labours and discoveries of our great metallurgists.

The knowledge and the experience of our engineers, our chemists, our scientific and practical iron and steel workers, has been freely and ungrudgingly communicated to the world in our Transactions. Great value and authority has been accorded to the papers and discussions of the Institute by scientific men; in evidence of which I may quote the numerous references to, and quotations from, our Journal in technical works in this and the European continent. The rapid progress in the development of the Bessemer process has been materially contributed to by the expositions of Sir Henry Bessemer and his co-workers, made at the meetings of this Institute, and published through its medium. A striking example of the progress which has been effected in the manufacture of steel may be noted in the statement by the Duke of Devonshire, in his address to the members of this Institute in 1869—but twenty-one years ago—in reference to the Siemens process for making steel in the regenerative furnace:—"In the present state of the experiment, it can only be enumerated among the projects now on trial, the further progress of which will be watched with interest." The production of open-hearth steel last year was, in Great Britain alone, 1,429,169 tons. This was very largely employed in the building of ships; the gross tonnage of ships launched in the United Kingdom in 1889 having been 1,288,251 tons, of which 1,215,276 tons were of steel—steel made by the open-hearth process being the material generally adopted.

It is very interesting, too, to note the rapid progress of the basic process, invented and developed by Messrs. Thomas and Gilchrist, materially assisted by other members of this Institute.

Progress of the Basic or Thomas-Gilchrist Process during the Twelve Months ending 31*st December*, 1889.

The total make of steel and ingot iron from phosphoric pig during this period amounts to 2,274,552 tons, being an increase over the make for the previous twelve months of about 321,318 tons, and making the total production of basic steel to this date 10,845,000 tons.

It will be noticed that of the above-mentioned make of 2,274,552 tons, no fewer than 1,764,639 tons were ingot iron, containing under ·17 per cent. of carbon.

The makes of the various countries for the twelve months ending 31st December 1888 and 31st December 1889, respectively, are as follows:—

	1889.		1888.	
	Total.	With Under ·17 per Cent. Carbon.	Total.	With Under ·17 per Cent. Carbon.
	Tons.	Tons.	Tons.	Tons.
England	493,919	348,828	408,594	276,476
Germany, Luxemburg, and Austria	1,481,642	1,185,323	1,276,070	1,026,033
France	222,392	159,271	222,333	158,223
Belgium and other countries .	76,599	71,217	46,237	32,300
Totals . . .	2,274,552	1,764,639	1,953,234	1,493,032

With this 2,274,552 tons of basic steel were produced some 700,000 tons of slag (containing about 36 per cent. of phosphate of lime), most of which was used as a fertiliser.

Our works are well known to members of the trade in the United States, and I think we have collectively done something, as British iron and steel manufacturers, to justify to some extent the opportunities you are now so generously opening up to us. The rulers of my native land have not all been wise, or generous, or unselfish. Their treatment of the American iron trade in the last century was stupid, illiberal, and grasping. I read in a history of the United States of America, that in 1750 the manufacture of iron in New England, which had already been started with some prospect of success, was forbidden by an Act of the English Parliament under very severe penalties. It states, "The ironmongers and smiths of Birmingham were in favour of the importation into England of American iron in an unmanufactured state, on the ground that all the ironworks in Great Britain were inadequate to supply even half the quantity of that metal required in the several manufactories, and that the colonists would be encouraged to take English goods in exchange for their raw material." But the manufacture of iron was suppressed, native enterprise was stifled, and the price of commodities in America was enhanced in order that English manufactures might be protected, and English merchants might grow rich. The scarcity of charcoal—the only fuel employed at that time for the smelting of iron—caused a falling off in the production, and England became in consequence a large importer of iron.

We have grown wiser since that time; we can see that in this wide world there is room for the iron and steel manufactures of England, the United States, and Germany. The world must have iron and steel. That nation is the wisest and most civilised which consumes the most of them. The United States and England are not likely, at all events, to dispute this assertion. The average consumption of iron (pig iron) per inhabitant in the United States, taking the population at sixty-three millions, was in 1889 about 302 lbs. per head; in the United Kingdom of Great Britain and Ireland the average consumption was about 303 lbs. per head, but of this a large quantity was exported in the form of machinery. In the United States it goes almost entirely into consumption.

The consumption is steadily increasing, having risen, between 1881 and 1889, in the United States from 270 lbs. to 302 lbs.; in the United Kingdom from 287 lbs. to 303 lbs.

England has atoned for its short-sightedness in 1750 by pouring into this continent copious supplies of iron, which have been used in the construction and exploitation of a marvellous railway system. But naturally the rich and inexhaustible mineral wealth in iron and coal which this country holds within its shores gave birth to an iron and steel industry which has grown and developed with a rapidity and a vigour that is known only in this wondrous land. The industrial force of a nation can be estimated in a considerable measure by the quantity of iron it consumes. Iron is coming so largely into use for constructive purposes, that this demand is sure to continue and to increase. The average consumption of iron per head in 1889 by the population of the world was about 14½ lbs.; but if the world's inhabitants generally were to consume the same quantities of iron per head as the inhabitants of the United States, the consumption would amount to about 207 million tons per annum, or nearly 9½ times what it is at present!

Although vast multitudes of the human race will long rest outside the sphere of the producers of iron and steel, there are regions now rapidly awaking to a knowledge of the resources which the engineer has it in his power to develop within them. In South America, in Australia, China, India, and South Africa, we can see possibilities of demand which lend themselves to a consumption of iron and steel that shall task the resources of our great industries in either continent. While the United States continues to find its market in ever-growing demands from a civilised and prosperous people at home, we in England shall have in more distant fields, easily accessible to us from our insular position, a great market for our produce. We can look forward, each in our own sphere, to a growing commerce, to cope with which our united skill, aided by invention shared and knowledge freely communicated, shall confer lasting benefits on the world.

Mr. James F. Lewis, the Chairman of the New York Reception Committee next spoke. He said that after the words of welcome from a gentleman who had come three thousand miles to deliver that address, it would seem as though there was nothing more to add to it; but the visitors were in the hands of a Local Committee, and he knew that the Local Committee would not feel that he had done his duty as chairman unless he echoed the words of Mr. Carnegie; and he would also take the liberty to echo them for all his brother Local Committees, probably to the number of twenty-five, whose hands the visitors would pass through before they had returned to New York. He was, therefore, about to enlarge that word of welcome given to them by Mr. Carnegie, and make it so large that it would extend in a circle from New York to Alabama; to the shores of Lake Superior, and back to New York again. The visitors were in the hands of an organisation that had laid out a programme of entertainment for them that they hoped would be pleasant and enjoyable. He wished to say that they had endeavoured to think of all the details in such a way as to give such information as they would no doubt look for; but he would add that, as they were in America with the Yankees, they must adopt the style of the Yankees, and ask questions.

Mr. ARCHIBALD BLUE, Deputy Minister of Agriculture under the Canadian Government, said: I have come at the instance of the Government of Ontario, whose officer and servant I am, to extend to you an invitation to visit that important Canadian commonwealth before you return home. Word has reached the Government that some of your number purpose passing through our country on their way down from the mining regions of Minnesota, Wisconsin, and Michigan, and that a short stay is likely to be made at the nickel and copper mines of Sudbury. An earnest hope is entertained, not only that they may be led to prolong the period of their stay in Ontario, and extend their visit to other mineral districts, but also that the whole body of the Institute may be prevailed upon to come and do likewise.

It would be a pleasure to the Government to have an opportunity of showing civilities to the members of the Institute, representing as they do one of the greatest of the great industries of the mother-land; and I am also authorised to state that in this agreeable undertaking the Government would be heartily joined by the Board of Trade of the city of Toronto, the strongest and most representative organisation of its kind in Canada. You, gentlemen, are specially interested in iron, and in the supply of iron ores. You are now to a large extent dependent upon foreign countries for the qualities of ore needed in the production of steel, and it may concern you to know that in Ontario we have immense ranges of iron ores, mostly of the magnetic variety, touched as yet only by the hammer of the prospector, and awaiting enterprise and capital to develop them and convert them into the best grades of iron and steel. You are expected to visit the famous Vermilion range in Northern Minnesota, the annual output of whose mines has risen in five years from a few thousands to more than half a million tons. Well, sixty miles away, in the province of Ontario, we have the same geological formation, and extensive ore bodies have recently been discovered there; while a hundred miles to the north-westward, midway between Lake Superior and Lake of the Woods, there is a mountain of rich magnetic iron ore, several miles in length, and claimed to be well suited for the production of Bessemer steel. We have also large bodies of clean magnetic ores in the eastern part of the province, and others not so clean.

You have heard something of the existence of nickel ore in our province, and it is proposed, I understand, to spend a few hours at the mines and smelting-works of the Canadian Copper Company of Ohio, the Hussey Vivian Company of Wales, and the Dominion Copper Company of Canada, all of which are in the vicinity of Sudbury. The experiments of Riley and Hall with alloys of nickel and steel are familiar to members of the Institute, for they were luminously presented by those gentlemen at your meeting of May of last year. Since then, as I happen to know, those experiments have received the careful attention of one high in the counsels of the Government of the United States, and promptly following the tests upon armour-plates made at the Annapolis Navy-yard a few days ago, we saw nickel placed on the free list, and a million dollars voted by Congress to purchase a supply of the metal, to be used in the manufacture of nickel-steel for plating the new battle-ships. Here, in the United States, the impression appears to prevail that the ore exists in very limited quantity, and that unless it is snatched at once, a more favoured nation may get in ahead and take all. It is therefore pardonable in the members of the Iron and Steel Institute, living four thousand miles away, if they are no better informed than our neighbours on the extent of Ontario's resources in nickel ore. The fact is, we do not know their exact extent ourselves, but we know that great ranges of the ore have been discovered over an area of several hundred square miles, and from its occurrence in a particular formation we have reason to believe that it exists throughout a region several thousand square miles in extent.

In nickel and iron ores Ontario is especially rich, and we think the time is opportune for the British ironmaster to seek to do there in his own industry what the British farmer settler has so successfully done in agriculture. We are fellow-citizens with you, and where our institutions differ from those of the United Kingdom, we believe they differ, not for worse, but for better. Sometimes we have thought that in your enterprises and investments abroad you have shown greater partiality to the older son, Jonathan, than to the younger, Johnny Cannuck. But we recognise the laws which govern business operations, and we do not doubt that success will come to those who work and wait for it, if they are worthy of it. We are living on excellent terms with Brother Jonathan, in spite of seeming rivalries at Ottawa and Washington in the building of tariff walls, and we have some of his capital and skill employed in utilising our mineral wealth. But much more is needed; and if abounding deposits of iron and nickel ores are a temptation to the gentlemen of the Iron and Steel Institute, I know that I can give to them from the Government of the province of Ontario, and the Board of Trade of the city of Toronto, the assurance of a kindly and hearty welcome to the country of the great lakes.

Dr. A. C. SELWYN, F.R.S., Director of the Dominion Geological Survey of Canada, said that all necessary facilities would be given by the Dominion Government to make a visit of the members of the Institute to Canada agreeable.

The minutes of the previous general meeting of the Institute were then read, confirmed, and signed by the President.

Election of President.

The President announced that the Council had decided to recommend that they should elect for the coming period of two years a distinguished scientific man to follow himself, and he had the satisfaction of announcing that Sir Frederick Abel, who was distinguished for his investigations in chemical science, had consented, subject to approval by that meeting, to occupy the chair for the next two years. He asked those who were in favour of the election of Sir Frederick Abel to signify the same by holding up both hands.

The proposal was adopted unanimously.

New Members.

Mr. J. Cartmell Ridley (Newcastle-on-Tyne) and Mr. T. M. Percy (Wigan) were, on the motion of the President, appointed scrutineers of the voting papers, and reported, on the completion of their scrutiny, that the following candidates for membership in the Institute had been duly elected:—

Adamson, Robert Lawrence	London.
Albright, John Francis	London.
Allan, James	Coatbridge, N.B.
Alonso, Fernando	Bilbao, Spain.
Andrew, Frederick	Lincoln.
Arbel, Pierre	Rive de Gier, France.
Armstrong, William Irving	Hexham.
Banks, Henry	Wolverhampton.
Bearcroft, Reginald	London, S.W.
Bennie, James	Glasgow.
Berkley, George	London.
Bevan, Isaiah	Llanelly.
Birkbeck, Frank	Penclawdd, nr. Swansea.
Birkbeck, George	Penclawdd, nr. Swansea.
Birkbeck, Henry	London.
Bond, Geo. Creswell	Staveley.
Bowen, Thomas	Morriston, Glam.
Bright, William	Fairwood, Glam.
Brooke, F. H.	Huddersfield.
Bruce, John Munro	London.
Bruce, Wm. Duff	Westminster.
Chernoff, Dimitis	St. Petersburg.
Cliff, Walter	Leeds.

Colley, Thos. Hairs	Leeds.
Commans, Robt. Edden	London.
Craig, James	Kilmarnock, N.B.
Crawhall, Lionel Wm. T.	Alston, Cumberland.
Davis, William	Swansea.
Day, Richard	Horbury, nr. Wakefield.
Dobson, J. M.	London.
Drummond, S. R.	Bradford, Yorks.
Dunnachie, Archibald Hendry	Glenboig, Coatbridge, N.B.
Evans, David	Llanelly.
Faber, Edward Grey	Upper Norwood, London.
Feldtmann, Gottlieb Heinrich	St. Bees.
Fincken, C. W.	Barnsley.
Firth, Wm.	Leeds.
Fry, John Pease	Darlington.
Green, Wm. Rowe	Newport, Mon.
Glenn, Joseph Barber	Poultry, London.
Grigg, Richard	Middlesbrough.
Guilleaume, Max	Mulheim-on-Rhine, Germany.
Guy, Henry Augustus	Sheffield.
Head, Archibald Potter	Middlesbrough.
Hill, Alfred	Middlesbrough.
Hulton-Harrop, Wm. Edward M.	Shrewsbury.
Hunter, Wm.	Glasgow.
Jack, Alex. M.	Sheffield.
Jackman, Joseph	Sheffield.
Johnson, Herbert Alfred	Manchester.
Jones, James	Swansea.
Kennedy, William	Glasgow.
Loomis, Burdett	Hartford, Conn., U.S.A.
Maclaren, John Finlay	Glasgow.
Markham, Charles Paxton	Chesterfield.
Marston, Charles	Wolverhampton
McCullum, John	Doncaster.
McClure, Samuel	Sharon, Penn., U.S.A.
Mungall, James	Dunfermline, N.B.
Needham, Joseph	Sheffield.
Newton, Joseph	Sheffield.
Nice, Alfred Slater	Newmarket.
Patrick, A. C.	Johnstone, N.B.
Pearson, Cecil Hope	London.
Peech, Henry	Sheffield.
Perkins, Simon, Junr.	Sharon, Penn., U.S.A.
Philip, Arnold	Richmond, Surrey.

Phillips, Chas. D.	Newport, Mon.
Phillips, John Wm.	College Hill, London.
Piedbœuf, Paul	Düsseldorf, Germany.
Plowden, Sir Wm., M.P.	Portland Place, London.
Powell, Horatio Gibbs	Wolverhampton.
Radcliffe, Wm.	Sheffield.
Robinson, Richard	Sheffield.
Rogerson, Wm. E.	Durham.
Russell, Henry Augustus	Sheffield.
Rowley, Brooke	Halifax.
Ryland, William	Sheffield.
Scarf, Fredk	West Bromwich.
Schwarz, Cecil Ritter von	Bengal, India.
Senhouse, Humphrey Patricius	The Fitz, Cockermouth.
Sharp, Thomas Budworth	Birmingham.
Sochor, Baron Friedrich Rudolph	Leeds.
Spearman, J. J.	Sharpsville, Penn., U.S.A.
Stanley, Hon. Edward Lyulph	Dover Street, London.
Steel, James	Edinburgh.
Summers, John	Stalybridge.
Sykes, Ezra	Huddersfield.
Talbot, George	Aix-la-Chapelle, Prussia.
Tannett, John Croysdale	Leeds.
Taylor, Joseph Garside	Sheffield.
Thackray, George Edward	Johnstown, Pa., U.S.A.
Tinn, Cecil Godfrey	Pontnewynydd, S. Wales.
Warbuck, Fredk. Elias	London.
Watts, Edmund Harvey	London.
Wheeler, E. A.	Sharon, Penn., U.S.A.
Whitwell, Joseph Fry	Saltburn-by-the-Sea.
Wood, Percy	Halifax, Yorks.
Worrall, W. E.	Middlesbrough.
Wragg, John Downing	Burton-on-Trent.
Young, John	Baillieston, N.B.
Younger, John	Glasgow.

New Members of Council.

The Secretary announced that Sir William Thomas Lewis, Aberdare; Mr. Alexander Thielen, Ruhrort, Germany; Professor Roberts-Austen, C.B., F.R.S., London; Mr. Andrew Carnegie, Pittsburgh; and Mr. R. A. Hadfield, Sheffield, had been added to the list of the Council. He also announced the retiring members of Council.

The following paper was then read:—

THE DEVELOPMENT OF AMERICAN BLAST FURNACES, WITH SPECIAL REFERENCE TO LARGE YIELDS.

BY JAMES GAYLEY, BRADDOCK, PA.

THE development of blast furnace practice in America in the direction of large yields is mainly the history of our working since the year 1880, as the advancement that has been made in the last decade is greater than that made in the previous quarter of a century. A new era in the manufacture of pig iron began in 1880 with the putting in blast of the Edgar-Thomson furnaces. These furnaces at once leaped to the front as pig iron producers, and have maintained that position—with but one brief interruption—ever since. I shall, therefore, confine myself mainly to a description of these works, showing the changes in design and practice by which these results have been achieved. In order to show more clearly the progress that has been made since 1880, I shall refer briefly to the best work that was done in the ten years previous to that time. The Struthers furnace, in Ohio, was one of the first to attract attention in the matter of large outputs. This furnace was 55 feet high, 16 feet diameter of bosh, 9-feet hearth, stock line about 8 feet 6 inches. The fuel was raw coal. This furnace, in December 1871, made 1602 tons of iron, and in January 1872 made 1642 tons. The best output in a single week was 400 tons. By March 1876 the product had increased to 2032 tons. The furnace was blown by one engine, with an air cylinder 72 inches in diameter, and 4-feet stroke. The only change made from 1871 to 1876 was the addition of a second blowing engine. The size of the hearth was much in advance of the construction usual at that time; and was, in fact, as large as would now be put in a furnace of the same size. The good results obtained at this furnace were largely due to the fact that the manager, Mr. Thomas W. Kennedy, broke away from the traditional practice of regulating

Note.—All tons are gross tons of 2240 lbs., and all temperatures are Fahrenheit.

the quantity of blast by the pressure gauge, and substituted therefor the revolutions of the engine—a practice that obtains to-day.

A record of No. 1 furnace of the Isabella furnaces, located at Pittsburgh, has been furnished me; and, as these furnaces have since become famous in the annals of pig iron manufacture, a return of their work at that time will be found interesting. I have not been able to secure the lines or detail construction of this furnace, but the general dimensions were:—Height, 75 feet; diameter of bosh, 20 feet; cubical capacity, about 15,000 feet. The furnace was "blown in" in January 1876, and continued in blast until May 1880—making a total output of 117,575 tons of pig iron, or an average of 2264 tons per month. The consumption of coke per ton of iron averaged 3000 lbs.; the temperature of blast ranged from 1000 to 1100 degrees, with a blast pressure of 4 to 6 lbs. No record was kept of the amount of air blown. The Lucy furnaces, owned by the firm of Carnegie, Phipps, & Co., are also located in Pittsburgh. These furnaces ranked with the Isabella as the largest producers in America. I have been so fortunate as to obtain the lines of one of these furnaces, the Lucy No. 2, built in 1877, which I show in fig. 1. The general dimensions are as follows:—Total height, 75 feet; diameter of bosh, 20 feet; diameter of hearth, 9 feet; cubical capacity, 15,400 feet. This drawing shows a bell 12 feet in diameter; but Mr. H. M. Curry, who was then manager of the works, advises me that the bell generally in use was 11 feet in diameter. During a part of the blast a bell 12 feet in diameter was tried, but not proving to be of advantage, was abandoned. In the construction of this furnace, the noticeable features are a narrower hearth and a wider top than are now put in furnaces of the same cubical capacity; but at that time it was considered an excellent shape, and certainly did produce some excellent results. As early as 1878 this furnace had made a monthly output of 3286 tons, on a coke consumption of 2793 lbs. per ton of iron; and in one week shortly afterwards made 821 tons. The furnace was "blown in" in September 1877, but after running a few months was blown out in order to repair the bosh walls, which, for some reason, had rapidly given way. In the following March the furnace was again started, and continued in blast for nearly thirty-four months, making in this time an output of 92,128 tons, or an average of 2737 tons per month, on an average coke consumption of 2865 lbs. per ton of iron. For the first twelve full months the output was 33,552 tons, on a coke consumption of 2850 lbs. The amount of air blown was 16,000 cubic feet per minute, which entered the furnace through six 8-inch tuyeres; the temperature of blast was 915 degrees, and the pressure at tuyeres 5 lbs. The ore mixture yielded in the furnace 60 per cent. iron. The work that was done at this furnace was unquestionably the best, all things considered, that had been accomplished prior to the starting of the Edgar-Thomson furnaces.

Furnace "A" of the Edgar-Thomson works was originally a charcoal furnace at Escanaba, Michigan, but was removed and erected on its new foundations in 1879. The dimensions of this furnace, as will be seen by a reference to fig. 2, are as follows:—Height, 65 feet; diameter of bosh, 13 feet; diameter of hearth, 8 feet 6 inches; cubical capacity, 6396 feet. Six tuyeres, 4 inches in diameter, were used; these, projecting 7 inches inside the crucible, made the efficient diameter of hearth 7 feet 4 inches. The tuyeres were placed 5 feet 6 inches above the hearth line. In Vol. VIII. of the "Transactions of the American Institute of Mining Engineers," a description is given of the "blowing in" and subsequent working of this furnace, by Mr. Julian Kennedy, who was then manager of the works. The following points of construction are emphasised in his paper. The interior lines make very small angles with each other—so small, in fact, that the arc of a circle drawn from the top to the tuyeres will not deviate more than two inches from the lines as given. Particular attention was given to rounding the angles. The bosh is located about midway in the furnace, making the bosh wall very steep. The batter of this wall was 1⅜ inch to the foot, which is equivalent to an angle of 84 degrees. The furnace was lined throughout with small bricks. The stove equipment consisted of three Siemens-Cowper-Cochrane stoves, 15 feet in diameter by 50 feet in height. This furnace was "blown in" in January 1880. The ore mixture consisted of Tafna, M'Comber, Pilot Knob, and Somorrostro ores, yielding in the furnace 54·5 per cent. iron. The output of the first full week was 442 tons, and reached 537 tons for the fourth week. The output and consumption of coke for the first few months are as follows:—

Month.	Tons.	Lbs. Coke per Ton of Iron.
January	1,634	2,675
February	2,236	2,306
March	2,762	2,306
April	1,586	2,482*
May	2,226	1,945

In June the furnace was changed to making spiegel, and has been used almost exclusively ever since for making the various grades of spiegel and ferro-manganese. The average weekly output for the month of March was 644½ tons, one day having been lost.

The best week's output was 671 tons. The blast was heated to an average temperature of 1050 degrees, the utmost that the stoves would furnish; the pressure at the tuyeres was 6¼ pounds. The engine equipment consisted of two vertical blowing engines, one of which was new, with a blowing tub 84 inches in diameter and 4 feet stroke; the other, a small and inefficient one, had been brought from Escanaba. But it so happened that Furnace "B" was in course of construction, and one of the engines belonging to this furnace was in good running order; consequently, the Escanaba engine was retired from active service, and these two larger engines were used to supply Furnace "A."

The volume of air forced into this furnace was 15,000 cubic feet per minute, or as much as was used elsewhere for furnaces of more than twice the capacity. The results obtained were surprising, and it is no wonder that the pig-iron-making world regarded them with an astonishment amounting, in many cases, to incredulity. Considering the cubical capacity of the furnace, the rate of driving was certainly excessive; and, that the results on fuel were so low, as compared with the subsequent consumption on larger furnaces where the same practice was employed, is mainly due to the narrow furnace stack. These fuel results, as I shall presently show, were much lower than any obtained from the larger furnaces in the next five years; and, had a distinction been then made between rapid driving on the one hand and excessive driving on the other, many American furnaces would have reduced their outlay for fuel enormously.

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* Furnace was stopped for four days.

In fig. 3 is shown a drawing of the second furnace erected at these works, of which the general dimensions are as follows:—Height, 80 feet; diameter of bosh, 20 feet; diameter of hearth, 11 feet; cubical capacity, 17,868 feet. The brickwork of the stack was held together by 8-inch iron bands supported by staves of T-iron, forming a crinoline. The bosh walls were banded in the same manner. The walls of the hearth were surrounded by solid cast-iron plates, securely bolted, no cooling plates of any kind being used. The stock was distributed at the top by a double bell, in which the central cone remained stationary; while the outer conical ring, being lowered, cast the stock towards the wall and centre of the furnace. One feature of this construction, differing from that of other furnaces then using coke for fuel, was the large hearth, providing more space for combustion. As originally planned, the hearth was 9 feet in diameter at the bottom, and sloping up to the tuyeres; but, before building, Mr. Kennedy changed the plan, so that the inwalls of the hearth would be straight, making the diameter 11 feet. There was, moreover, an increased number of tuyeres, eight being used, and an increased elevation of tuyeres above the hearth level, all of which were necessary for rapid driving and large yields. In the anthracite district large hearths had been tried at a much earlier day. As early as 1854 the Thomases, at the Crane Iron Works, in the Lehigh Valley, had tried enlarging their hearths by pulling back the tuyeres until a diameter of 11 feet was reached. From this experiment they obtained such excellent results, both as to output and quality of metal, that they afterwards adopted as a standard that the diameter of the hearth should be one half the diameter of the bosh. But while the hearths of various furnaces had been enlarged after they were in blast, yet no American furnace up to that time had been constructed with so large a hearth as this one at the Edgar-Thomson works. In another respect this furnace was well prepared by its designers for a high productive capacity, viz., in its equipment. Fire-brick stoves of the most approved type were erected. Substantially-built blowing engines were provided, and they were rendered efficient by an ample supply of boilers—a point in which other furnaces were then sadly lacking. At the same time all the flues and mains were constructed sufficiently large, and in the most substantial way. In fact, no furnace previously erected had been planned on such a liberal basis; consequently, large yields were to be expected.

The furnace was put in blast in April 1880. In the following month an output of 3718 tons was made, and the next month showed 4318 tons; thus fully justifying the claims of its designers by eclipsing all previous records. The detailed record of the work done by this furnace during the earlier months of the blast is as follows:—

Months.	Tons.	Lbs. Coke per Ton Iron.
April	2,723	2,536
May	3,718	2,574
June	4,318	2,344
July	4,345	2,706
August	4,601	2,811
September	4,221	2,757
October	4,722	2,736

It will be noticed that the consumption of fuel increases as the summer months advance. These works, being located on flat land along the Monongahela River, are more particularly affected than elsewhere by the content of moisture in the atmosphere, it being nearly twice as much in summer as in winter. While this fact has always had an important bearing on our fuel economy, yet, in this case, another feature of the practice tending to increase the fuel consumption was the increased rate of driving; the volume of air blown having been gradually increased to 30,000 cubic feet per minute, engine measurement, taxing alike the efficiency of the engines and the stoves. However, a high productive capacity was aimed at, and an output of 4722 tons in a month was certainly marvellous at that time, and was either regarded as incredible or accounted for on the supposition that the furnace had been transformed into a cupola by melting large quantities of scrap. But the furnace records show that the yield of ore mixture was 55 per cent. iron. The weight of limestone was 25 per cent. of the weight of the ore. An analysis of the cinder shows:—

	Per Cent.
Silica	32·31
Alumina	13·20

The limestone contained a very small quantity of magnesia. The blast entered the furnace through eight bronze tuyeres of 5½ inches diameter, and was heated to a temperature of 1100 degrees. The silicon in the iron averaged about 2 per cent. The rapid wear of the furnace walls, through the use of such a large volume of air, gradually increased the consumption of coke to over 3000 lbs. per ton of iron. At the end of the first twelve full months the output was 48,179 tons, on an average coke consumption of 2859 lbs. per ton of iron. The second year showed an average consumption of 3200 lbs. of coke, with a decrease in yield. The upper brickwork of the stack having given way, the furnace was blown out after a blast of two years and five months, having made a total product of 112,060 tons, on an average coke consumption of 3149 lbs. per ton of iron.

The results obtained in this blast determined several important changes in construction. It was seen that the crinoline structure afforded inadequate protection to the brick work of the stack, in consequence of which it was torn down and replaced by an iron jacket; also, that the bosh walls should be protected so as to preserve as far as possible the original lines, and the hearth be surrounded with water-cooled plates. The double bell was also found to possess no special advantage, and was abandoned. These changes were introduced in the furnace next erected at these works. But, before leaving this furnace, I wish to emphasise the bearing that the practice of rapid driving, begun on Furnace "A," and further developed on this one, had on the general practice of this country. The large outputs obtained from this furnace by the use of a large volume of air, was a matter of common knowledge; the practice of fast driving soon became the accepted one, and with our national ardour it was prosecuted enthusiastically. In every direction, engines that had been running along for years at a methodical gait, were oiled up and started off at a livelier pace; new boilers were added; the old iron hot blast stoves, not supplying sufficient heat, were torn down and replaced by the more efficient fire-brick stoves. At many works rapid driving degenerated into excessive driving. True, the outputs increased; so also did the consumption of fuel, and that at a surprising rate, until it was thought well nigh impossible to produce a ton of iron with 2600 lbs. of coke.

Mr. E. C. Potter of Chicago sounded the note of warning in 1885, and great credit is due to him for demonstrating that large outputs and low fuel consumption are compatible. Since then a marked change in our practice has taken place, and the volume of air blown has been greatly diminished.

Although the practice of rapid driving has been much decried, yet in many ways it has resulted beneficially. It has brought in an equipment of hot blast stoves, boilers, engines, &c., sufficient to accomplish a large amount of work without a constant strain on every part—a condition very rare prior to 1880; and it has also developed a construction of the furnace stack, by which larger outputs from a single lining can be obtained with less irregularity in the working.

In fig. 4 is shown a furnace of different construction from either of the preceding, it being my purpose to present successive types of construction rather than changes in the same furnace. We find this furnace constructed with special regard to the better protection of the brick-work of hearth and bosh. The general dimensions are as follows:—Height, 80 feet; diameter of bosh, 23 feet; diameter of hearth, 11 feet 6 inches; stock line, 17 feet; bell, 11 feet; cubical capacity, 21,478 feet. The bosh is placed at about the centre of the stack, making very steep walls. The hearth is also made wider by 6 inches than in the furnace previously described. The hearth walls are surrounded by cast iron plates with a coil inside for the circulation of water. Around the bottom of these plates is a gutter, through which waste water from the cooling plates flowed, affording better protection to the bottom of the hearth. Above this row of plates, at the tuyere breasts, is another circle of cooling plates, partially inserted in the brick-work. The walls of the bosh are encased in a jacket of wrought iron, ½ inch in thickness. This jacket is bolted on to the mantle. The bosh walls inside the jacket were made but 22½ inches thick, so that the cooling effect of the air currents on the jacket would prevent any very rapid wear of the brick-work.

It is a fact well known in our practice that the best records are obtained within the first year of the blast, as the walls are not then affected to any great extent by wear. With the better protection afforded by more recent construction, this difference has not been so marked. This furnace was put in blast in 1882, and, in the second month, made the large yield of 6045 tons, on a coke consumption of 2617 lbs. In the first twelve full months the output was 65,947 tons, on an average of 2570 lbs. of coke per ton of iron, thus exceeding, by over 11,000 tons, the best output that had previously been obtained in the same time from any furnace at these works, and with a much smaller consumption of fuel. The record for the best month during this period was 6131 tons, on a coke consumption of 2387 lbs. per ton of iron. The amount of air blown was 27,000 cubic feet per minute, which was heated to an average temperature of 1000 degrees. The pressure of blast at the tuyeres varied between 9 and 10 lbs. After a blast of seventeen months' duration this furnace was blown out, having made a total output of 90,317 tons, on an average coke consumption of 2613 lbs. per ton of iron,

For what reason this furnace was blown out I do not know, since the consumption of fuel, even in the last two months of the run, did not increase more than 100 lbs. above the average. The furnace records afford no explanation of the cause. As a matter of fact, the results were much better than any obtained for a number of years afterwards. They serve, also, to show how very materially a slight protection afforded to the furnace walls affects the output and the consumption of fuel.

As illustrating the effects of an excessive volume of air, I will mention a furnace put in blast two years later—of practically the same dimensions and protected to the same extent, but blown with 33,000 cubic feet of air per minute—which made an average output of 5000 tons per month, on a coke consumption of 3000 lbs. per ton of iron. This is the largest amount of air that I know to have been forced into any furnace. The fuel consumption is what might have been expected, as the furnace was driven at such a rapid rate that the imperfect reduction of the ores in its cooler parts necessitated the completion at a temperature sufficiently high for the CO_2 to react on the carbon.

In the next drawing, fig. 5, is shown a different arrangement for maintaining the bosh walls. The lower part of the hearth is surrounded by cast iron plates. On the top of these rests a water-cooled corset jacket, fastened together with links, and banded at the upper and lower ends by iron bands, 6 inches wide and 1 inch thick. The wrought iron bosh jacket is dispensed with; and, in its stead, are two bands of water-cooled plates, covering the greater portion of the brick-work. These are held in place by bands at the top and bottom, and also by being inserted a short distance in the brick-work. The tuyere fittings are unique. The arrangement, as shown in the drawing, consists, first, of a large oval block, made of cast iron, and water-cooled. Fitting into this, with sufficient space left for a clay packing, is a large bronze cooler, oval-shaped at the outer end, but with a circular opening at the inner end for the insertion of the tuyeres. This cooler was supported by trunnions resting on the block, by means of which the nose could be either elevated or depressed. The tuyeres were shaped to make a ball-joint connection with the cooler, so that a horizontal delivery of the blast could be obtained with any inclination of the cooler. The adjustment was such that the tuyeres were placed in a staggered position, there being as much as 6 inches between the centre lines of each adjacent tuyere. The reason given for this placing of tuyeres was "to obtain a greater area of contact between the fuel and the air." No such benefit, however, was derived, and the tuyeres were subsequently placed on the same level.

The dimensions of the furnace are shown in the drawing. The cubical capacity was 16,680 feet. In February 1885 the furnace was "blown in." The volume of blast was rapidly increased until, in the following month, it reached 31,000 cubic feet per minute. The blast entered the furnace through eight tuyeres, 7 inches in diameter, and was heated to an average temperature of 1200 degrees. The pressure at the tuyeres was 8½ lbs. The average monthly output from March to August inclusive was 5122 tons on a coke consumption of 2874 lbs. per ton of iron.

As this was the third blast for the same furnace (a companion furnace to that shown in fig. 3), a comparison with the record made at the same relative time on the first blast will show the effect of different rates of driving on the fuel economy. In the first blast the coke consumption was 2600 lbs., with a volume of air of 24,000 cubic feet per minute; in this blast it has risen to 2850 lbs., through an increase in the volume of air of 7000 cubic feet.

On taking charge of these works in October 1885 I endeavoured to reduce the volume of blast in order to diminish the consumption of fuel. The reductions were made slowly, until the volume was 28,000 cubic feet per minute. Many attempts were made to reduce it still further, but as each attempt was invariably met by great irregularity in the working of the furnace, further efforts in that direction were abandoned. The volume of blast was therefore maintained steadily at 28,000 cubic feet, and the temperature, which before had been quite variable, was maintained more uniformly. At the same time the cinder, which was quite basic, was made less so.

As a result of these changes the output increased to an average of 6050 tons per month, on a coke consumption of 2400 lbs. per ton of iron; but after a three months' trial the furnace was suddenly shut down, with a full working burden, for a period of twenty-one days, on account of labour troubles. After it had resumed, and the bad working incident to such a shut down had been remedied, the furnace made an average monthly output of 5700 tons; but the consumption of coke had advanced to 2600 lbs., and continued at that figure till the end of the blast. The furnace was blown out, on account of the upper lining being destroyed, after a blast of twenty-three months. The total output for the blast was 118,000 tons, on a coke consumption of 2705 lbs. For the first twelve full months the output was 64,998 tons, on a coke consumption of 2677 lbs. per ton of iron.

In fig. 6 of the drawings is shown a combination of figs. 4 and 5, in the construction of cooling jackets. From the top of the corset jacket down, the construction is an exact duplicate of the one just described. Between the corset and wrought iron jackets a row of water-cooled iron plates is inserted in the brickwork. There were eight sections in the circle, all being connected together, and the water was fed from the high-pressure main. The advantage of a high water-pressure on this kind of plate is shown by the fact that not a single one was lost during the entire blast.

The interior shape of this furnace differs very materially from those previously shown, having been made to conform, as nearly as possible, to a furnace at the South Chicago works, which was then giving excellent results in regard to both output and consumption of fuel. The bell is increased in diameter, and the upper walls are drawn in, making a less diameter at the stock line. The bosh is 22 feet in diameter, the total height 80 feet, the cubical capacity, 18,950 feet. There are eight tuyeres, each 5 inches in diameter.

This furnace was "blown in" in September 1885, and in one week from starting, the volume of blast was 27,000 cubic feet per minute, and was at this figure when the furnace came under my management. Within the next two months I reduced this volume to 22,000 cubic feet, which was heated to a temperature of 1300 degrees.

The product for October was 6320 tons, and for November 6306 tons, on a coke consumption of 2396 lbs. In December, the output on the decreased volume of blast increased to 6451 tons, and the consumption of coke had fallen to 2172 lbs. During the months of January and February, 1886, we were unfortunately compelled to shut down for thirty-three days. In the month of March the output was 6352 tons, on a coke consumption of 2105 lbs. For the first twelve full months the output was 74,475 tons, on an average coke consumption of 2250 lbs. per ton of iron. During the last year that the furnace was in blast, the volume of air was gradually increased to 27,000 cubic feet per minute. The inwalls were much worn, and the grade of iron had become variable; but with the increased volume of air, the working became very uniform. In the last eight months of the blast, the consumption of coke had risen to 2500 lbs. After a blast of twenty-six months, the furnace was blown out, having made a total output of 150,374 tons on an average fuel consumption of 2342 lbs. per ton of iron. At no time in the blast did the coke consumption reach 2600 lbs., except in the third month before blowing out. The best output obtained in any single month was 6730 tons.

While these records were much better than any previously obtained at the same works, it was evident that had the bosh walls been entirely protected with cooling plates, still better results would have been got. When exterior cooling jackets only are used, the preserving of the furnace lines depends wholly upon the carbon coating which is deposited upon the brick-work as the latter wears away; in fact, were it not for this protection, the bricks would last but a very short time indeed. When this coating increases in thickness, the furnace works far more regularly and economically; and in a furnace considerably worn, the thickness of this carbon wall is to a great extent the measure of its economical working. We have repaired bosh walls where only 6 inches of the brick-work remained; but inside was found this coating, 18 to 20 inches thick, firmly set, and far more difficult to penetrate with a drill than the firmest brick-work. But, while the thickness of this coating may be increased at will, yet it can only be done at the expense of fuel; and so unstable is the formation, that the expensive operation of building up—extending over months—may be dissipated in a week or two, by running the furnace on an acid cinder.

In fig. 7 is shown the same furnace as in fig. 5, with the bosh entirely protected by cooling plates inserted in the brick-work. A comparison of the two drawings will show the changes in construction. The hearth has been widened to 11 feet diameter. The diameter of bosh is also increased 1 foot, and the stock line is reduced 15 inches. The hearth is protected by water-cooled plates, which, from their slanting position, admit of a greater thickness of brick-work at the bottom. These plates are practically automatic, as under an expansion of the brick-work they slide up. In some cases they have raised as much as 3 inches. In the bosh are four rows of bronze cooling-plates, eight plates forming the circle, and each plate having two water courses. In the two lower rows each plate is fed separately; in the upper rows, two plates are connected together. We have found, from quite a number of tests, that the water circulating through these plates increases 10 degrees in temperature. Cast iron cooling-plates are also placed between the tuyeres, the number of the latter being reduced to seven, 6 inches in diameter. The cubical capacity of the furnace is 17,230 feet.

This furnace was "blown in" in March 1887, and in April made 5591 tons, on a coke consumption of 2105 lbs. In May and June the output was small, a stoppage occurring on account of a shortage in the coke supply. In July the output increased to 6243 tons, and in September reached 7064 tons, on a coke consumption of 1993 lbs. The volume of air blown was 24,000 cubic feet per minute, heated to an average temperature of 1200 degrees. This furnace continued to do excellent work until the following December, when a stoppage of four and a half months occurred, pending an adjustment of the wage question. In the nine months that the furnace had been in blast previous to this stop—and including the stoppage on account of coke shortage—the fuel consumption did not exceed 2160 lbs. per ton of iron. In May, operations were again resumed. While the output soon reached the former figures, yet the coke consumption was rarely reduced for any one month—even to the end of the blast—below 2300 lbs. In the period extending from October 1888 to January 1890 the average monthly output was 7000 tons, on a coke consumption of 2350 lbs. During this period the volume of air had been increased to 27,000 cubic feet per minute. The temperature of blast was still maintained at 1200 degrees. The average pressure of blast at the tuyeres was 8 lbs. On account of the brick-work in the bosh being very much worn, the furnace was blown out after a run of 2 years, 7 months, and 17 days—exclusive of the time the furnace was banked. The output for the blast was 203,050 tons, on an average coke consumption of 2342 lbs. per ton of iron. The output for the first twelve full months was 72,554 tons, on a coke consumption of 2230 lbs. For the second twelve months, during which no stoppage occurred, the output was 83,219 tons. The best output made in any one month was 7680 tons.

It will be seen by the preceding description that the results both in output and economy of fuel have been materially affected by the long stops that the furnace was subjected to. Under a continuous run, much better results would have been got.

The advantages of this system of cooling the bosh were very marked, and although quite a number of plates were lost from various causes during the blast, yet, when a new one was inserted, the furnace invariably showed an improvement in its working.

In the next drawing, fig. 8, is seen the same construction of hearth and bosh applied to one of our larger furnaces. In fact, the furnace just described was remodelled after this one; but for the purpose of comparing two consecutive blasts on the latter, I have placed it earlier. This furnace was built in 1885–86. The total height is 80 feet; the diameter of hearth, 11 feet; the diameter of bosh, 23 feet. The bell is 12 feet in diameter, and the stock line 16 feet. The cubical capacity is 19,800 feet. The construction of hearth and bosh is the same as in the furnace just described. There are seven tuyeres, each 6 inches in diameter.

The furnace was started in October 1886. The record for the next three months is as follows:—

Months.	Tons.	Lbs. Coke per Ton of Iron.
November	6,735	2,128
December	7,494	2,105
January	8,398	1,935

From January to May inclusive, the average monthly output was 8150 tons, on a coke consumption of 1980 lbs. The volume of air blown was 27,000 cubic feet per minute, which was heated to an average temperature of 1200 degrees. The pressure at the tuyeres varied from 9 to 10 lbs., and was generally the latter figure when the outputs were largest. In June, the furnace was banked for eight days on account of scarcity of coke, as previously mentioned. As this furnace had been doing such excellent work, the others were banked first, in order to give this one, if possible, a continuous blast; but the supply of coke failed, and although the stop was comparatively a short one, yet, as a result of it, the coke consumption increased to 2300 lbs. The monthly output from this time, up to January 1888, was 7400 tons, when a second stoppage on account of labour troubles occurred. The length of this stop was sixty-seven days; and, although the product was exceptionally large, even to the end of the blast—reaching in some months to over 8000 tons—the consumption of coke increased to an average of 2450 lbs.

It is greatly to be regretted that our work does not show an uninterrupted blast; since our records show, in nearly every case, a decrease in output and an increase in fuel consumption from 150 to 200 lbs. per ton of iron, as a result of each "banking up."

A portion of the upper lining giving way in August 1889, the furnace was blown out. The last full month (July) in blast showed an output of 6491 tons. The furnace was in blast—exclusive of the two stoppages I have mentioned—two years, seven months, and ten days, and made in that time 224,795 tons of iron, on an average coke consumption of 2317 lbs. The output for the first twelve full months was 88,940 tons on 2150 lbs. of coke. The efficiency of the cooling-plates in the bosh walls was very marked in this case. The exterior brick-work was in as good condition as at the beginning of the blast, neither a crack, nor a brick forced out of position, showing anywhere. After the stack was cleaned out a careful inspection was made. The bosh walls were found to be in good condition. A measurement at the bosh line showed that the furnace had widened out 18 inches, but with such uniformity that the widest variation shown by the gauge did not exceed 2 inches. From the bosh line to the top of furnace the wear was very much greater. The furnace was relined without delay, and after a two weeks' drying out was put in blast on September 25, 1889, just seven weeks from the time of blowing out. The construction is the same in every particular, except that the diameter of the bosh is reduced to 22 feet, and the stock line to 15 feet 6 inches. The lining runs straight from bosh to stock line. This change reduced the cubical capacity to 18,200 feet. The same number and size of tuyeres are used. The volume of air blown is 25,000 cubic feet per minute, a reduction of 2000 cubic feet from that used in previous blast. Beginning with October, the record of monthly outputs and coke consumption to the present time is as follows:—

Months.	Tons.	Lbs. Coke per Ton of Iron.
October 1889	6,521	2,450
November „	9,097	1,897
December „	10,603	1,756
January 1890	10,536	1,737
February „	8,954	1,859
March , ...	9,941	1,845
April „	10,075	1,847
May „	10,035!	1,884

The best output for any one week is 2462 tons. The temperature of blast averages 1100 degrees, and the pressure 9½ lbs. The temperature of the escaping gases is 340 degrees. An average composition is—

CO, 27·5 per cent., CO_2, 11·7 per cent.
CO, CO_2, 0·42 per cent.

Counting the time the furnace was running in the first blast, and up to the end of May 1890 in the second blast, including also the time spent in relining, the period covered is three years and five months, and in that time this furnace has made an output of 301,205 tons, a record which is unparalleled. In the month of May, this, together with a companion furnace of precisely the same dimensions, made an output of 20,192 tons, on an average coke consumption of 1882 lbs. per ton of iron. The ores used are from the Lake Superior region, and yield through the furnace 62 per cent. of iron. The proportion of limestone carried is 28 per cent. of the ore burden, and about 1200 lbs. of cinder are made per ton of iron. The average analysis of the cinder is as follows:—

Silica	33·00 per cent
Alumina	13·00 „

The stone used contained but a very small quantity of magnesia. The silicon in the iron averages 1·60 per cent., the iron being run into ladles and sent to the converting mill direct. The suitableness of the metal for this "direct process," as we term it, will be appreciated from the fact that under the rigid system of foundry grading—by the fracture—the average percentage of Nos. 1 and 2 grades from all of our furnaces for the first five months of this year was 95 per cent., and the analyses of one hundred ladles, filled consecutively from the furnaces, show an average content of sulphur of 0·023 per cent.

I shall not undertake to say what these furnaces will accomplish on an uninterrupted blast, but I believe the day is not far distant when we shall be able to show a record of 300,000 tons from a furnace in three years, and on a single lining.

In the period covered by the last decade there are three steps in the development of American blast furnace practice that might be mentioned—first, in 1880, the introduction of rapid driving, with its large outputs and high fuel consumption; second, in 1885, the production of an equally large amount of iron, with a low fuel consumption, by slow driving; and third, in 1890, the production of nearly double that quantity of iron, on a low fuel consumption, through rapid driving.

In the following table I give a summary of the preceding data:—

ABSTRACT OF RESULTS.

Designation of Furnace.	Year in which Furnace Commenced the Blast.	Cubical Capacity.	Volume of Air per Minute.	Total Output from Blast.	In First Twelve Full Months.			
					Output.	Average Daily Output.	Average Coke Consumption.	Capacity for One Ton of Iron per Day.
		Cubic Feet.	Cubic Feet.	Tons.	Tons.	Tons.	Lbs.	Cubic Feet.
Isabella . . .	1876	15,000	...	117,575	28,000	76	3,000	197
Lucy, fig. 1 . .	1878	15,400	16,000	92,128	33,552	91	2,850	169
Edgar-Thomson, fig. 2	1880	6,396	15,000	...	...	*71	*2,400	90
,, ,, ,, 3	1880	17,868	30,000	112,060	48,179	132	2,859	135
,, ,, ,, 4	1882	21,478	27,000	90,317	65,947	180	2,570	119
,, ,, ,, 5	1885	16,680	†31,000	118,000	64,998	178	2,677	90
,, ,, ,, 6	1885	18,950	22,000	150,374	74,475	204	2,250	92
,, ,, ,, 7	1887	17,230	24,000	203,050	‡72,554	198	2,230	87
,, ,, ,, 8	1886	19,800	27,000	224,795	88,940	244	2,150	81
,, ,, ,, 8	1889	18,200	25,000	...	§113,000	310	1,920	59

* Estimated.

† After running nine months the volume of air was reduced to 28,000 cubic feet.

‡ The second twelve full months, by reason of a continuous blast, shows an output of 83,219 tons on 2396 pounds of coke.

§ Estimated from record made to date.

Note.—The actual record for fig. 8 blast of 1889 shows for the first year in blast 113,526 gross tons on a coke consumption of 1892 lbs. per ton of iron.

DISCUSSION ON MR. GAYLEY'S PAPER.

At the invitation of the President,

Sir **Lowthian Bell** said—If the creation of the Iron and Steel Institute had been followed by no more important results than the opportunities it has afforded to those occupied in a common pursuit, of comparing the results of their individual experience, it has done good work. It has taught us, among other things, that any knowledge we may impart to each other must not be regarded as a mere gift, but rather as an exchange, the value of which cannot be estimated by the sum of the two, but by entirely new factors, requiring the united experience and knowledge possessed by the giver and the receiver.

Speaking from my own experience, this has been amply illustrated in the frequent, and, to myself, the most beneficial relations which I have been fortunate enough to establish with a large number of the leading manufacturers in the United States of America, as well as with numerous other friends in various countries of Europe. Lastly, I am indebted to my connection with this Institute for the opportunity of again visiting the United States, and seeing once more those gentlemen from whom I have received so much attention, and towards whom I feel myself drawn by ties of the warmest friendship.

It is unnecessary to assure the author of the paper before us how grateful the members of this body must feel for the thoroughness of the work he has performed. Iron manufacturers have now been accustomed for some time to follow, as closely as the nature of the operation permits, the action of the blast furnace, and to study the laws which regulate its action. The results, however, which have been communicated to us this morning may well suggest the idea whether we have, in our previous estimates, not overlooked some of the conditions involved in smelting the ores of iron; for we have not only to consider the low consumption of fuel mentioned by Mr. Gayley, but the hitherto unparalleled large production of iron from one furnace.

Thinking that it might interest others as well as myself, I have examined the figures given us by this gentleman, and have compared them with those of furnaces working under very different conditions, and I hope to be able to show you that it is not necessary to look for any new law to account for what, at first sight, seems little short of the incredible.

For this purpose I will omit for the present all the first examples quoted in the document before us, and go straight to the last, which my friend, Mr. Gayley, has properly reserved for winding up his most interesting communication.

The problem before us is to account, if we can, for a furnace producing about five times as much iron as we have hitherto made in Cleveland from our poorer ore, and about twice as much as has been obtained from our hæmatite furnaces of like dimensions in England. And all this has been performed in the particular case before us with an expenditure of 16·80 cwts. of coke per ton of iron of a high average quality.

The consumption of coke per ton of iron depends on its quality, or on the more or less perfect manner of its combustion, or on the amount of work it has to perform.

Now, so far as concerns Connellsville coke, which was the coke used in the case before us, there is nothing to be set down to superiority of quality; for, instead of containing 5 to 7½ per cent. of ash, like the coke of Durham, it has rarely less than 10 per cent., and sometimes more, of this impurity.

The completeness of combustion of the carbon we have to deal with is, of course, judged by the amount of carbonic acid in the gases. Now, when we compare the heat obtained from each unit of coke, estimated as nearly as I have been able from Mr. Gayley's data, partly because the carbon as carbonic acid is, in relation to that as carbonic oxide, slightly below that which is often found in the gases from a Cleveland furnace, partly because the temperature of the blast is not quite so high, and partly because the ash is higher in the American than in the English coke, a somewhat larger amount of duty is obtained from the latter. The effect of these is evidenced in the following figures:—

One unit of coke afforded of heat—

	CLEVELAND. Calories.	LUCY FURNACE. Calories.
Carbon burnt to carbon oxide . . .	2032	1898
Part of above burnt to carbonic acid .	1672	1626
Heat in blast	727	617
Totals .	4431	4141

showing a difference of 7½ per cent. in favour of the Cleveland furnace. It may be here remarked that the relation between carbon as carbonic acid to carbon as carbonic oxide in the Cleveland furnace is as 1 to 2·11 against 1 to 2·35 in the Pittsburgh. On the other hand, the actual quantity of carbon as acid in the former is 5·97 cwts. against 4·80 cwts. in the latter furnace. The generation of carbonic acid being almost entirely due to the oxidation of carbonic oxide by the act of reduction, the difference in quantity at the Pittsburg furnace is due to the carbonic acid generated being returned to the condition of carbonic oxide, involving thereby a loss of 5600 units or thereabouts per ton of iron. I believe 5·97 cwts. of carbon as carbonic acid per ton of iron, is about the full quantity capable of being produced by the reduction of the ore.

The furnace with which this Pittsburgh furnace has been compared performed its duty under an entirely different class of circumstances, as may be seen from the two columns of figures which follow :—

	CLEVELAND.	LUCY.
Cubical contents	25,500	18,200
Temperature of blast . . .	704° C.	593° C.
Coke consumed per ton of iron .	19·99 cwt.	16·80 cwt.
Limestone ,, . . .	11·00 ,,	9·03 ,,
Ore ,, . . .	48·00 ,,	32·26 ,,
Weight of blast per ton of iron .	87·15 ,,	71·20 ,,
Weight of gases ,, . .	119·47 ,,	100·10 ,,
Temp. of gases ,, . .	250° C.	171° C.
Tons of iron for 1000 cubic feet space of furnace, per week . .	21·57	128·00 avr. 3½ yrs. 2333
Slag per ton of iron . . .	28·00	10·71
Calories produced per ton of iron .	88,577	69,569

The differences in the various factors are met by corresponding variations in the appropriation of heat under the various items. These are set forth in the next two columns, the equivalents in coke being also given :—

	Cleveland. Coke.	Pittsburgh. Coke.
Reduction of peroxide of iron	33,108=7·47	33,108=8·00
,, metalloids in pig	4,174=0·94	2,631=0·64
Dissociation of carbonic oxide	1,440=0·33	1,460=0·35
Fusion of pig iron	6,600=1·49	6,600=1·59
Evaporation of water in coke	275=0·06	83=0·02
Decomposition of water in blast	2,380=0·54	2,333=0·56
Expulsion of carbonic acid of lime	4,070=0·92	3,094=0·75
Reduction of the carbonic acid to CO	4,224=0·95	3,488=0·84
Fusion of slag	15,400=3·48	5,890=1·42
Carried off in gases	7,166=1·60	5,013=1·21
Heat lost by radiation, convection, tuyere water, &c.	9,740=2·21	5,869=1·42
Totals	88,577=19·99	69,569=16·80

A very important source of loss of heat may be involved in that carried away in the escaping gases, and the lessening of this bears directly on the large make of the furnaces referred to by Mr. Gayley, and accounts for a large portion of the saving effected by the hot blast. Thus when furnaces of 48 feet in height were blown with cold air, nearly 25 per cent. of the effective heat of the coke—say 9 cwts.—was carried off in this way, but by heating the blast to 485° one-half of this was saved, and by doubling the capacity of the furnace the loss carried away in the gases was reduced to less than 2 cwt. of coke. So far as these Pittsburgh furnaces are concerned, I have since my arrival in New York heard the large make and the economy of fuel set down to the facility with which the Lake Superior ore was reduced. In my opinion, this is doubtful. In my experiments I instituted a large number of comparative trials of the readiness with which different ores part with their oxygen. Of all, I believe the ore of our Cleveland hills retains its oxygen with the greatest tenacity; but in spite of this, reduction, so far as it is effected in the upper zone, is accomplished during its passage through the first 10 feet of its descent in an 80-feet furnace. I have, it will be perceived, limited the amount of reduction effected in these 10 feet of depth, because I think a large portion of oxygen—about 25 per cent. of the whole—is retained until the region of the tuyeres is reached. Into the cause of this, time will not permit me to enter upon the present occasion. One cause of the gases escaping at a high temperature is the undue rapidity with which they pass through the solids during the descent of the latter. From this it might be inferred that in the Pittsburgh furnaces, with their rapid driving, there would be a tendency to a great loss from this cause, whereas the contrary is the fact, seeing the gas in a given time is three times as great in them as it is in those of Middlesbrough. Now, if we take account of the difference in the cubic capacity, about four times as much gas is passing through a given space in the American furnace as happens in the English. The mode of accounting for this apparent anomaly is the only question left for me to bring under your notice. To do this, we may neglect the chemical action going on in the interior of the furnace, and consider the cooling of the gases as effected by their meeting, during their ascent, the descending current of cooler solids.

Let us suppose a tall vessel filled with fragments of small balls, say of calcined Cleveland ore. A current of hot air is passed through them, and in time the air will flow out of the top at about the temperature at which it enters, the difference being due to loss through the sides of the vessel. We now commence to withdraw the balls, say at the rate of twenty in a minute, adding a similar number at the top. The escaping current is slightly cooled, which means that a loss of heat at the top is still going on, but the balls withdrawn are still at a high temperature. We increase the rate of withdrawal to 200 per minute, by which the gases fall to atmospheric temperature, but 200 balls being too many for the current of hot air to raise to the desired temperature, we must retard the rate of withdrawal until the desired elevation is obtained. It follows, from this experiment, that there is a given ratio somewhat between 20 and 200 balls per minute which gives the best result.

In an old blast furnace of 6000 cubic feet, smelting Cleveland ore, 36·7 tons of iron were weekly made per 1000 cubic feet of capacity; the temperature of the escaping gas was 451° C., the blast being 485° C. The loss in coke was 5 cwts. in the escaping gases. After increasing the capacity to 15,500 cubic feet, the loss from this cause was reduced to 2½ cwt.; but instead of obtaining 36·7 tons of iron per week per 1000 feet of capacity, we only got about 22 tons; the heat-intercepting power of our furnace charges being equal to reducing the temperature of the gases to 310° C.

It is quite reasonable, however, to suppose that materials might be introduced at the top with a more powerful heat-intercepting faculty than Cleveland iron. I believe that your compact ore, containing one-half more iron than ours, possesses this property, and in consequence your gases escape at a temperature of 160°, which I estimate represents a loss of only ·93 cwt. of coke.

If the rate you are driving at represents the position of equilibrium I am describing, you will lose heat and waste coke either by driving more slowly or more quickly than you are now doing.

In conclusion, as I have partly intimated, I am not in possession of all the data necessary for exact calculation. Substantially I hope my figures will prove correct, but it might be well if Mr. Gayley would himself look over my estimates.

Mr. Edgar S. Cook (the Warwick Iron Company, Pottstown, Pennsylvania) said, that a few days ago Mr. Gayley had sent him a copy of his paper, with the request that he should be prepared to make some remarks. After a careful reading of his paper, he concluded that Mr. Gayley had about exhausted the subject, at least as far as the coke practice was concerned. When a single furnace of 18,000 cubic feet capacity could be made to produce 113,000 gross tons of iron in one year, with an average fuel consumption of 1920 lbs. of coke per ton of iron, little more remained to be said. In view of the vast improvements within the last ten years—which, by the way, were not all due to improved construction and equipment—he would be a bold prophet indeed to put himself upon record by prophesying that the end had been reached. To the average mind it would appear that the possible advances of the future could not compare with those of the past. Nevertheless, there was plenty of scope for earnest endeavour to bring the average work of the many furnaces up to the high standard shown to be possible by the record of the Edgar-Thomson furnaces, as made public by Mr. Gayley.

It had occurred to him that while Mr. Gayley had so fully treated of the large and splendidly equipped furnaces using coke fuel and burdens of the rich Lake ores, the progress made by the smaller furnaces using anthracite fuel might not be without some interest.

During 1872 the State of Pennsylvania produced 968,453 net tons of anthracite iron, and only 388,011 net tons of coke iron out of a total product for the United States of 2,854,558 tons. The Pennsylvania furnaces for 1880 made 1,237,930 tons of anthracite and 801,817 tons of coke iron out of a total product of 4,295,414 tons; while in 1889 the furnaces situated in the anthracite district of Pennsylvania were credited with a yield of 1,793,639 tons, and the coke furnaces with 2,371,652 tons, out of a total of 8,516,079 net tons for the whole country. Previous to 1882 little or no coke was used in admixture with anthracite. Since 1883 the use of a certain quantity of coke had become almost universal in the anthracite districts. Many furnaces, while in close proximity to the anthracite fields, used coke fuel exclusively; so that of the 1,793,639 tons credited to the anthracite districts for 1889, only 344,358 tons were made from anthracite exclusively. It would thus appear that the anthracite iron industry was a decaying one, soon to disappear from the face of the earth, unless the coal railroads adopted a more liberal policy for the future than had characterised them in the past. Coke fuel cost more per ton in the district referred to than coal. The preference shown to the former as a blast-furnace fuel was due to the greater ease with which the furnace was controlled, and the less risk of costly scaffolds and chills. No one who was not practically acquainted with the subject was likely to appreciate the difference in the actual management of furnaces using coal and coke, respectively. The difficulties attending the former greatly exceeded the latter. Mr. Gayley could no doubt speak feelingly on that subject, and he might be willing to attribute part of his deserved success in coke practice to the severe training obtained in the anthracite part of the business. At the same time, if the anthracite furnace was successfully and economically handled, the profits were greater or the losses smaller than if the more expensive coke was used. The development in furnace practice east of the Alleghany Mountains within the last ten years would compare favourably with the advancement made in the west, notwithstanding that the yearly product of any single furnace sank into insignificance when compared with the vast outputs obtained at Pittsburgh and Chicago.

As the Edgar-Thomson furnaces fairly represented the progress in coke practice, the Warwick furnace at Pottstown, Pennsylvania, might illustrate the improvement in the anthracite practice, although it was by no means alone in the work. He assumed the management of that furnace in December 1877. It had been built and first blown-in during 1875, and had run with indifferent success, averaging about 20 tons of iron per day. The furnace was originally 16 feet bosh and 55 feet high. The bosh-line was afterwards reduced 6 inches and the height increased 6 inches, the capacity being about 5500 feet. Previous to 1878 furnaces of this size were making from 150 to 250 tons per week, the latter figure being considered rather exceptional. From 1¾ to 2 tons gross of coal per ton of iron was about the average fuel consumption. The Warwick furnace in 1878 produced 17,148 tons of 2268 lbs., an average of nearly 330 tons per week, using 2912 lbs. of coal per ton of iron. The ore mixture yielded 45·4 per cent., and the furnace was blown with 8300 cubic feet of air per minute, heated in iron pipe stoves to 855° Fahr. For 1879 the product was 19,387½ tons, or about 373 tons per week, with 2912 lbs. of coal per ton of iron. The ores yielded 44·7 per cent.; 8300 cubic feet of air per minute was used, heated to 850°. The blast terminated in January 1880, the furnace having run 107 weeks, and making 37,400 tons of iron. In starting, it blew on an old inwall. This gave way directly above the boshes, and the gas penetrated to the red brick shell, necessitating blowing out. At the time, this work was quite a revelation, so far as the use of anthracite fuel was concerned, and was the subject of wide remark, occurring as it did about the same time that the Lucy Furnace was showing the possibilities of coke, and creating a stir in the iron circles, not only of that vicinity, but of the country at large. Comments were numerous, and some, of course, unfavourable. It was asserted that no furnace brickwork could stand such over-driving—although the difficulty with anthracite furnaces had always been to drive them hard enough—and that the manager, with youthful ambition, was striving to make a record for himself at the expense of his company. As their president and directors were more than satisfied with the financial results, under the most unfavourable trade conditions hitherto experienced, those criticisms did not cause much discouragement.

To illustrate the other side, he could not do better than quote from a letter of Mr. P. L. Weimer, a gentleman widely and favourably known in blast-furnace and engineering circles, published in the *Bulletin of the American Iron and Steel Association.* Mr. Weimer wrote :—"That the record above given is exceptionally good none will deny, and that it demonstrates the value of anthracite as a furnace fuel is equally obvious; but there are several features especially worthy of consideration." Referring to the year 1879 he continued:—"The output, which averaged 372·83 tons per week, is greater than the average of coke furnaces of equal size, using the rich ores from Lake Superior, and will compare, in proportion to size, with any coke furnace; the ores averaged 44·7 per cent., while the Lake ores employed by coke furnaces average 60 per cent. of iron. Second, The fuel consumption with ores yielding less than 45 per cent. is noteworthy, 2912 lbs. per ton of iron. Third, The small amount of air per lb. of fuel, 73·63 cubic feet. Fourth, The moderate heat of blast employed, 850°. Fifth, The apparently excessive amount of stoppages" —(in explanation, he would say that the stoppages were largely due to cleaning boilers, no extra set being built at that time; they stopped two weeks each year for boiler cleaning). "Sixth, The regularity of the furnace operation, neither the maximum nor minimum weekly output varying from the average more than 12 per cent. Only 6½ per cent. of the iron made was other than No. 2 and 3 mill, and but 1 per cent. being mottled and white. Seventh, The variety of ores employed, necessitating corresponding changes in flux."

It would be well to bear in mind that at that period chemistry was but sparingly employed; only a few furnaces, the Warwick among the number, making use of the help afforded by analysis. The furnace was relined, no particular changes being made in the construction, and "blown-in" in the latter part of March 1880. They started off well enough, making about 400 tons per week, but the blast was of short duration. During that year, the adverse critics of the improved practice apparently had the best of the argument. The manager was placed in an embarrassing position. Though firm in the belief that all would come out right in the end, yet, as "success is the best evidence of success," he could not then offer the convincing proof. In 1875 the furnace was built with bosh walls five feet thick, strengthened by upright wrought-iron brickstaves. That construction was retained in 1880, as light bosh walls were then unknown, or, if considered at all, were looked upon as a hazardous experiment. With the increased volume of air blown and a lower fuel consumption (he never ran by pressure of blast, but always by volume), the brickwork melted rapidly, forming huge pockets or cavities above the tuyeres. These filled with finely divided ore and coal-dirt, and the mass slipping at once into the crucible, chilled the furnace. Had they then been as well informed as to the use of the oil blowpipe as in later years, and had a device, only used at their furnace, termed the tuyere slagging-valve, been known, the mortification of a chilled furnace could have been avoided, although it was not probable that the furnace could have been profitably run. The only way he could account for the previous blast not developing the same trouble was by the fact that, for the first month of the blast, the furnace was excessively grey, making vast quantities of slag. The bosh walls became heavily coated—evenly distributed, fortunately—with a graphite covering. This protected and preserved the brickwork, and kept the boshes in good shape. When the furnace was blown out, the existence of this coating was plainly evident. It proved to be a blessing in disguise, considering the anxiety and worry caused by the overheated condition of the furnace.

Not to prolong that ancient history to too great a length, in recounting the trials of 1880, he would simply say that the bosh was finally fitted with vertical coils of 1-inch pipe encircling the whole circumference, and extending about 10 feet or so above the tuyeres. These coils were supplied with water, which was kept in constant circulation. The pipes were built in the 5-feet wall. The exterior, being in good condition, was not disturbed. The pipes were placed against the melted brick face, and from 12 inches to 18 inches of new brick protected them from the contents of the furnace. That was the first instance, in their vicinity at least, of a water-cooled bosh, and many were the curious comments made upon their placing the furnace in a spring of water. The furnace was put in blast in December 1880, and continued in blast 245 weeks, making a total of 101,385½ tons, or an average of 413·6 tons per week. That was an unusual total for an anthracite blast. It might or might not have been reached by larger furnaces. Many difficulties were encountered, but patience and close application overcame them. For a few months in 1881, they used one-eighth coke and seven-eighths anthracite; but as that small percentage of coke only added to the cost without giving any corresponding benefit, it was discontinued. They ran on anthracite exclusively until January 1882, when they commenced using one-fourth coke and three-fourths coal, which proportion they had continued until the present time. For the entire blast of 245 weeks, the ore mixtures averaged 50 per cent., the fuel per ton of iron 2912 lbs., and the air per minute was 8750 cubic feet, heated to 865° Fahr. The best average for three months showed 600 tons of iron weekly, with a fuel consumption of 2212 lbs. per ton of iron. The furnace was repaired in the autumn of 1885. New hot-blast stoves were built, four sections of the Durham pattern—6240 square feet of heating surface, replacing the two small stoves of only 3600 square feet of heating surface. The thick bosh walls were dispensed with, 22 inches of brick, strengthened by ½-inch wrought iron jacket, being adopted instead. The bosh coils, or water-cooled pipes, were retained, being placed between the jacket and the brickwork. The capacity of the furnace remained about 5500 cubic feet. They commenced to blow in December 1886, and blew out on May 28, 1889. During the blast of 180 weeks, they made a total of 107,595½ tons of iron, an average of nearly 600 tons per week. The ores for the blast averaged 53 per cent., the fuel 2665 lbs. per ton of iron, and the air was 11,050 cubic feet per minute, heated to 884°. The largest yearly product was 32,738½ tons, the smallest 30,045 tons. The best month's work was 679 tons of iron per week, made with 2464 lbs. of fuel per ton of iron, when 56·7 cubic feet of capacity made one ton of iron per day, thus slightly exceeding the driving of the Edgar-Thomson furnaces. For the largest year of the blast, 61·2 cubic feet of capacity made one ton of iron per day, and for the entire blast, including stoppages, &c., the average was 64·4 cubic feet of capacity per ton of iron per day, which would compare favourably with the best coke practice, considering the difference in the ores and the fuel used. As a suggestion relative to the capabilities of anthracite, he would add that for one week of that blast, 702 tons of iron being made, 55 cubic feet of capacity produced one ton of iron per day.

The Warwick Furnace, however, made a specialty of mill-iron, low silicon and low phosphorus, the silicon running from 0·4 to 0·6 per cent. in grey forge grades; the phosphorus being 0·30 to 0·35 per cent. The mottled and white iron made would not exceed 3 per cent. of the total product of any blast, No. 1 foundry being 7 per cent., and the remaining 90 per cent. being grey forge, open and close grain. Up to June 1889, no change had been made in the equipment or the size of the furnace since 1875, except the enlarged hot-blast stoves and an extra set of boilers in order to avoid stoppages for cleaning, one set being idle all the time. During the summer of 1889 the old furnace stack, brick-banded with iron, was torn down and a new steel shell was erected of 16 feet bosh and 70 feet high, with a crucible 8 feet 9 inches in diameter, the cubic capacity being about 8400 feet. A large Weimer engine and extra boilers were added to the equipment. They blew in on October 6, 1889, and had been in blast now nearly one year. The product would approximate 40,000 tons, the average fuel consumption to date being 2464 lbs. per ton of iron; the ore mixture 55 per cent., and the air per minute 14,000 cubic feet, heated to 900°. The largest work for any one month’ so far, averaged 823 tons per week, with 873 tons as the best week. The lowest fuel consumption for any five consecutive weeks was 2268 lbs. per ton of iron. For the first year of the enlarged furnace, 76 cubic feet of capacity had made one ton of iron per day, the largest week showing 67·4 cubic feet capacity per ton of iron per day, which was somewhat above the average of the smaller stack. Before the blast was completed they hoped to improve the record. The second year of a blast showed the best results. Whether the same would hold good during this blast, remained to be seen.

At this stage, the discussion was adjourned until the following day.

THURSDAY, OCTOBER 2.

The proceedings of the Institute were resumed to-day—the **PRESIDENT** in the chair. The discussion on Mr. Gayley's paper was resumed.

Mr. A. **THIELEN** (Ruhrort) said: In offering a few remarks on Mr. Gayley's valuable paper, I would point out the strongly contrasting conditions under which we have to work our blast furnaces in Germany, more particularly in the northern district, along the Lower Rhine. The native ores at our disposal contain about 45 to 48 per cent. of iron. They consist principally of the Dutch bog-ores, of burnt pyrites or Blue Billy, and various refuse from chemical works, which are largely used in the manufacture of basic pig. If we attempted to work our blast furnaces so as to attain a monthly production of 10,000 tons, like the Lucy Furnace, we should have to put through them a very much larger quantity of material than suffices in Pittsburgh. If for the Lucy Furnace we assume an output of 10,000 tons of pig iron, derived from 63 per cent. ores, and allow for a limestone addition of 25 per cent., then the entire blast furnace mixture will amount to 16,000 tons of ore, and about 3500 tons of limestone, making in all 19,500 tons. In Germany, on the other hand, if we take the average of our ores at 46 or 48 per cent. of iron, the ore burden alone will be 21,500 tons, and to this we must add 33 per cent. of limestone, or 7000 tons; hence we should be obliged to put 28,500 tons of material through the furnace to get 10,000 tons of product. In view of the poorness of our ores, if we should limit ourselves to the same quantity of material as goes through the Lucy Furnace, our output would not exceed 6200 tons.

But there is another essential difference of conditions which prevents our following the example of the American blast furnace. The native ores which we have to depend on are, as a rule, very fine. More than 25 per cent. of the ore in our blast furnaces is of a much finer size than peas, and sometimes as fine as dust. With this material we should be unable to work our furnaces at such a speed as is common to the Lucy Furnace. So long as we do not get other ores we are bound to use our low furnaces. At no great distance from our Lower Rhine district there is a great body of oolitic ore, which we hope to be able to use to great advantage when a projected canal is built, or as soon as we can induce the Government to lower its rates on rail freight.

The quantity of coke we require is considerably less than that used in the Lucy Furnace. With only 48 per cent. of iron in our ores, as against 63 per cent. in the ores of the Lucy Furnace, we do not use more than 17 cwts. of coke per ton of pig, with a temperature of blast at the tuyeres of 850° Celsius.

Another reason for our not being able to follow the American lead is that the managers of our Bessemer converters demand at least 1·8 per cent. of silicon in the pig, whereas American steel-workers are satisfied with 0·6 or 0·7 per cent. In striving to emulate American example in this respect, we encountered insuperable difficulties. Without entering into details, I will only mention that our converters use direct metal, in contrast to the usual American plan of using cupola metal, which has a higher initial heat. We have to compensate for the lower temperature by keeping the amount of silicon up to 1·8 per cent. I might add another point; we would not be quite satisfied with the costly luxury of relining our furnaces every three years. Thus far we have managed to keep our furnace linings in for thirteen to seventeen years. At the present time we have several furnaces which are working in their sixteenth or seventeenth year, and they still give satisfactory results.

Mr. E. W. **Richards** said: This history of the development of blast furnace practice in and about Pittsburgh is a most interesting one. Mr. Gayley's paper, and Mr. Cook's statement yesterday, show that there has been abundance of experience in blowing-in and blowing-out blast furnaces. What are the objects of, and what are the inducements for, this excessive driving? The paper shows us that the cost of doing so is enormous. Labour is dearer in America than in England, so that as much work must be got out of it as possible. But I believe that the charger at the Cleveland blast furnace handles as many tons of material as flesh and blood can well do, and keep up all the year round. So that if the production of a blast furnace is to be doubled, double the men must be employed. It therefore seems difficult to understand how this excessive driving can reduce the cost of labour very much. It is probable that an explanation may be found in the satisfaction felt by the owner in a margin of profit, which is so pleasant to see that he instructs his blast furnace manager to give him tons of pigs—of course at the lowest possible cost—but to give him tons of pigs. Then there is another reason for this fast driving, which to those engaged in it has a great fascination, and is a constant stimulus to exertion—a stimulus much indulged in here. I refer to the practice of trying to beat the record. Captain Jones was a man of great ability, industry, and energy; and we who knew him well sorrow to-day that he has passed away from us. I had the pleasure, some nine years ago, of visiting with him the South Chicago works. At that time they had a new and magnificent plant of blast furnaces. Mr. Potter had arranged a most powerful equipment of stoves, blast engines, and several batteries of boilers. Captain Jones wrote home to say, "Those boys at Chicago intend to beat our record." And they did. Then the boys at the Edgar-Thomson works made their powerful plant still more powerful, so as to beat the boys at Chicago. And so they went on, until in 1885, Mr. Gayley tells us, they forced in the enormous volume of 31,000 cubic feet of air per minute at a blast pressure of over 9 lbs. per square inch, and so overdid it that they burned 2677 lbs. of coke per 2240 lbs. of iron produced, and shortened the short and merry life of the blast furnaces. The members of the Institute will inquire when at Chicago, and will be very curious and interested to know, who has the record now—whether Mr. Carnegie or Mr. Potter. If Mr. Carnegie has it, he will probably be content with 100,000 tons of pig iron per furnace per annum. If not, then we shall hear of more water-blocks, more fire-brick stoves, more blast engines, more batteries of boilers. But the furnaces themselves will have to be of a very greatly increased capacity to work economically, having boshes at least from 28 to 30 feet diameter.

It will be interesting to make a short comparison of the internal form of the furnaces described in this paper, and to know where and how they differ from the English forms, so as to show what has enabled the American practice to produce what are really astonishing results. We are at once struck by the much larger diameter of the hearth of the American furnace, and it is primarily due to this enlargement of the hearth that the increased output is obtained. But this would be of no great advantage had not the pressure and volume of the blast been at the same time very largely increased. Look at the forms of the furnaces Nos. 2, 3, and 4, and you will see that they have very steep and narrow boshes, which my experience has led me to regard as extremely bad forms—so bad that a furnace with a steep and narrow bosh of 84 degrees, as on No. 3, could not work well and make a regular quality of iron at what we must now term, I suppose, slow driving. Indeed, such a form necessitates fast driving, so as to keep the materials in motion, and prevent scaffolding. Steep and narrow boshes favour the formation of an arched scaffold much more than a flatter bosh. The latter gives an arch of larger radius, much more difficult to form. This arched scaffold gives great trouble when the slip takes place. No doubt the English bell of from 11 to 12 feet diameter is better and much simpler than the complication shown in figure 3. One is gratified to see that Mr. Gayley has discarded this arrangement. The adoption of the 11-foot bell gives a 2-foot space all around for the material to pass. A diameter of throat of 15 feet is a good proportion for a 22-feet bosh. I am not at all in favour of small boshes. The descent of the material in a cylinder is difficult through close packing, so that the diameter from the throat downward, to the top of the bosh should constantly increase, and so release the material from a too close contact, and permit the free passage of the gases. This arrangement at the same time tends to increase the diameter of the bosh, giving greater capacity to the furnace, and favouring a greater production with less forcing.

Mr. Gayley has recognised this, because I observed yesterday, when he was reading his paper, that he said (at page 18): "From the bosh line to the top of furnace the wear was very much greater." Then a few lines further down he says: "The lining runs straight from bosh to stock line." I advocate more that form, making a 15-foot throat, and tapering down to a very large bosh, so that the materials unpack themselves and the gases pass readily through. The angle of the bosh should, in my opinion, not exceed 75 degrees, and may with advantage be as low as 70 degrees if the bosh is about 22 feet diameter. The lines of the furnace called No. 8 show a return to the English form, with the exception that the tuyeres are placed higher up. I would suggest that if the two great works before named still purpose continuing to compete for the record, the one which adopts the greater cubical capacity will win. Mr. Potter, of Chicago, has already contributed so much in bringing about the brilliant results now recorded that this first day of October 1890 will, in the future, be considered an epoch in blast furnace practice, and will be pointed to and cited as the goal obtained, after years of thought and labour, by many who have devoted time and vast sums of money to reach it. It would be of great service in this discussion if Mr. Potter would give us the results of his experience, for it must be evident that, being such a distance from supplies of fuel, he would give much attention to economy in that direction. There seems at the present moment to be a lull in the race of the rivals. They seem to have got as much out of 20,000 cubical feet of blast furnace as can be got with economy; and we have before us the fact that a furnace using 60 per cent. of mineral produces 2000 tons weekly, with the very low consumption of 1920 lbs. of coke per ton of 2040 lbs. of pig iron made, which is a result of a highly satisfactory character—one that reflects the very greatest credit on the owners and managers, and one of which they may justly be proud.

There is a very interesting feature arising out of this rapid driving. We know quite well that a blast furnace settles down in the course of a couple of months to a certain rate of driving, which gives a regular quality of iron, as in the case of the furnaces making Cleveland iron, 60 per cent. of which is of No. 3 quality, with a yield of 20 cwt. of iron to 20 cwt. of coke. Now, if that furnace be driven without increasing the coke, the quality of iron immediately falls off, and you have probably No. 4 forge;

and if driven a little faster yet, it falls to white iron. But the American practice of doubling the production, with nothing exceptional in the temperature of the blast, makes a ton of Bessemer iron to considerably less than a ton of coke—a result, I believe, never before attained. We must presume that this economy of fuel was an accidental outcome of fast driving. At what point of production was this observed? I have constructed several blast furnaces, some with hearths 10 feet in diameter, and some with 11 feet, and have made Bessemer pig iron for steel-making purposes up to 1000 tons weekly, without remarking any special economy—indeed, rather the contrary, although the temperature of the blast was maintained at about 1400 degrees. Is it more desirable, or more economical, to drive a blast furnace at a speed of 2000 tons per month, the wear and tear and all things considered, than to obtain that production from two furnaces? You must have a certain number of stoves to heat the blast, and a certain number of blast engines in order to give you the fuel required, and you must have the requisite number of boilers to work those engines; so that it is simply a question of the outer shell of the blast furnace that we have to consider.

And so I ask, is it desirable, all things considered, to drive the furnaces at such a rate—the paper showing us that the cost of doing so is enormous? Is the iron, when the furnace is driven rapidly, producing 2000 tons per week, as uniform in quality as when driven at 1000 tons? It is my belief that it is, because I find, after increasing from 600 to 1000 tons per week, the quality is as good in making 1000 tons as in making 600. And so one might infer that the quality would be as good when making 2000 tons as when making 1000. There are other points in this paper that I feel quite sure some other blast-furnace manager will talk about, and so I will not bring them before you, as I think that I have already sufficiently occupied your time.

Mr. E. C. **Potter**, Chicago, said he was quite sure his friend Mr. Richards had no intention of precipitating a Kilkenny cat-fight between the Pittsburgh boys and the Chicago boys. He wanted to assure him that the rivalry was a most generous one, and that each one of them had gained mutual advantage from their mutual comparisons of work. He wanted to say, though, that they had a record of furnace practice at Chicago which he thought would compare favourably, perhaps, with the magnificent work of the Edgar-Thomson furnaces. Although the figures were not quite so large, still, in comparison with the size of the furnaces, he thought they would furnish considerable food for reflection as to whether the very large furnaces were the ones with which they might expect to obtain the highest possible economy. This record, he was sorry to say, was not accomplished by the furnaces at South Chicago, but by one of the furnaces at the Union plant of the Illinois Steel Company. The furnace in question was comparatively a small one, containing about 8800 cubic feet capacity. It had made this year in a single week 1414 tons of Bessemer iron, and in a month over 5800 tons; and this rate of production had been continued for several months, showing that it was not merely a "spurt." The fuel consumption for this month was some 50 lbs. lower than the lowest Mr. Gayley had obtained—namely, 1680 odd lbs.; he did not remember exactly, but it was in that neighbourhood. Now the question that presented itself to his mind in considering the performance of this furnace, and not only *this* one, but all of the fifteen furnaces now owned by the Illinois Steel Company, was that they had found that invariably the smaller furnaces showed much the better work in regard to output, in comparison with their cubical contents and with their fuel consumption. The performance of the furnace he had just cited showed a product of nearly 2¼ tons of iron per each 100 cubic feet of capacity per day. Mr. Gayley's furnace, to equal this, must make over 12,000 tons per month, and he did not think that that was quite possible within the light of their present knowledge.

It seemed to him from these records (and they were borne out by the practice in Chicago and the West) that a moderate-sized furnace—say from 10,000 to 12,000 cubic feet capacity—must be the one from which they might look for the best records, considered economically. He could not say that he had come to this conclusion definitely as yet, as they had now under construction at South Chicago a new plant of furnaces of the largest size—the same dimensions practically as Mr. Gayley's. Those were 85 feet in height and 21 feet bosh, with a cubical capacity of about 18,000 cubic feet. Until they had operated those furnaces, and determined just what they could do in comparison with the smaller ones, he must withhold his judgment as to which was the best size of furnace for economical work. Of course, in considering this, locality played a very large part. He thought that in the case of the Edgar-Thomson plant, and its proximity to the coke region, where the fuel saving was not so great an item as it was in the West, undoubtedly very large furnaces, and very large outputs—reducing thereby the labour cost per ton and the item of general expenses—was the one for that locality; but for the West, and for Chicago in particular, they must save the fuel. That was the paramount feature in their furnace practice. He had noticed with very much interest Mr. Gayley's experiments on his furnace linings and also Mr. Richards' remarks on the same subject. He must say that he was entirely in harmony with Mr. Richards in his criticisms on the furnace linings. They had done a considerable amount of experimenting in Chicago, and it had been entirely in the direction of lowering the bosh.

The furnaces described in his paper * before the Institute four years ago, as some of them might remember, were of the high, steep-bosh kind. These gave very good results as to the driving, and as to the fuel economy, but the serious fault they found with them was, that for certainly the first six months of their life, they had considerable trouble, as Mr. Richards prophesied, with the sticking, and hanging, and scaffolding, until the furnace had cut its own lines; and then, during the first six months of the second year they usually got their best work out of it. To overcome this, they lowered the bosh of the furnace from 35 feet above the hearth level to 26 feet above the hearth level, all the other dimensions being the same. This flattened the angle of the bosh from 81° to 72°. This furnace behaved very well in regard to the scaffolding and hanging; they never had an hour's difficulty on that score. But the furnace absolutely refused to

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* "On the South Chicago Iron and Steel Works, with Details of their Cost, &c." *Journal*, No. I., 1887, p. 163.

drive, and consequently they did not get as good fuel results as they did from the rapid driving. This, of course, was a fatal feature in the Chicago practice. To overcome such a difficulty, they had this year put in blast a furnace on lines modified from those just stated by leaving the bosh height the same, 26 feet, and widening the hearth from 11 to 12 feet, giving them their old bosh angle of 81°. This furnace seemed to have accomplished all that they had expected, and it had been working very smoothly from the day of its going in blast, driving with reasonable rapidity, and showing very good fuel consumption. These two furnaces were now working side by side, and the last furnace he had spoken of was making from 100 to 150 tons per week more than the other, so that it seemed to him that they had very nearly solved the question of furnace lining for the material with which they had to work.

Mr. G. J. **Snelus**, F.R.S., said it was a great advantage to the English members to have had Mr. Gayley's paper placed in their hands before they started on their voyage, for it gave many of them an opportunity of carefully considering the paper, which they certainly could not have done amidst the festivities of which they had been called upon to partake since they had arrived in America. He had made it his duty to study the paper carefully, and he certainly was delighted with it. He could not express his thanks too strongly to the writer of the paper, and to the owners of the works, for the munificent way in which they had laid their results before them. He had endeavoured to find out the reasons for their wonderful output, and for their economical production of pig iron. The large yield, three times as much as they were getting from furnaces of nearly or quite equal capacity in England, with a saving of 20 per cent. of fuel, was, he ventured to say, a point which Englishmen could not afford to overlook; and if they could find out the reason why these results were obtained, by coming the long journey they had undertaken, he was sure they would be repaid for their trouble.

He had endeavoured to make a comparison between the several points in the practice at the Edgar-Thomson furnaces with their own practice in England, and he would take the items one after the other as rapidly as he could. First, with regard to the shape of the furnace. He was very pleased to see that No. 8 furnace, which had given those wonderful results, was a return to the old lines of most of their good English furnaces. Mr. Richards had already called their attention to this, and he could say for himself that if they were to place their West Cumberland lines upon the No. 8 furnace, they would find that they would agree with them in all particulars except that the furnace was smaller. The angle of the bosh was identical—75°. The position of the bosh was identical. The proportion of the hearth to the bosh and to the height of the furnace was about the same. So that, so far as regarded the shape of the furnace, he could not see much to account for the improvement which they had met with.

Then with regard to the fuel, Sir Lowthian Bell had said that the English fuel was better than they had at these furnaces. He was afraid he could not say quite so much for what they got on the West Coast of England, but still it was not much worse. They had a coke there which contained roughly on the average about 10 per cent. of ash, and from ¾ to 1 per cent. of sulphur. That was about the average of the coke they got in West Cumberland, and he thought that that was about the average quality of the Connellsville coke. So that they might put fuel on one side as not contributing to these wonderful results in any great degree. Then with regard to the ores, they were told that the ores yielded 62 per cent. of metallic iron. The Cumberland ores did not yield so much as that; they yielded probably 56 per cent. on the average. So that here was one point of advantage which they could not afford to overlook, for not only did the ore contain more iron, but it contained less earthy matter, and that, he took it, was a point of very great importance in producing large quantities of material quickly, because they had so much less slag to get rid of, and therefore they had to use less fuel to get rid of it. With regard to the slag, he found, as far as the composition of the slag was given, that there was little difference between the composition of West Cumberland slag, and that usual in the United States. But, as he had just said, with regard to the quantity, they were at a disadvantage, having to produce considerably more slag to melt and take away than they had at the Edgar-Thomson furnaces; so that this was one point where the latter gained. With regard to the composition of the gas, he found that in the Pittsburgh case it was practically the same as they had in England at most of their furnaces, so that this was no point of advantage. With regard to the temperature of the blast, they were told that it was 1100° Fahrenheit. Well, they were quite up to that in England—in fact, that was about the temperature which they regularly got at West Cumberland, so that in this there was no point of advantage. With regard to the pressure of the blast, however, there was certainly a very important point of advantage. They were blowing at West Cumberland, and had been for many years, a pressure of blast of 6 lbs. to the inch; but here, in America, they were told they had from 9 to 10 lbs. That, he took it, was a distinct and very great advantage in getting large outputs.

So far as the volume of the blast was concerned, it was quite evident that a very much larger volume of blast was blown through those furnaces than they were accustomed to deal with in England, and he knew it had been a common idea amongst English ironmasters that by increasing the volume of the blast and driving faster they did not economise fuel. He would come to that point later. Clearly, as regarded large output, their American friends had a decided advantage in the higher pressure of blast, and in the greater volume of blast. Then, with regard to the radiation of heat from the furnace, he thought that it was quite clear that they had a decided gain under this head, and he could not help thinking that this was one of the points where the saving in fuel was to be accounted for. It seemed to him quite clear that a furnace which was producing as much iron with one casing as they were producing in England with four must radiate a very much less quantity of heat than they did with the four furnaces, and therefore there was a very distinct gain, and probably more than they had been accustomed to allow. In reference to the composition of the material which was made, they were told, with regard to the iron, that it was made low in silicon—a little over 1¼ per cent. Here again, he believed, there was a distinct advantage. Some years back he had had an opportunity of proving that, because they were then able to get supplies of that wonderful material, Campanil ore, which contained only about 5 per cent. of silica, but which was very porous, and enabled them to drive their furnaces faster, to have less slag, and to get iron with less silicon. Some years ago he himself had driven furnaces with 1¼ per cent. of silicon, which they took direct to the Bessemer works. Unfortunately, the Campanil ore had become very scarce, and in Cumberland they could not afford to continue the use of it for admixture, and they had to fall back upon the local ores, which, although purer, were more silicious, so that they generally found that in making a non-silicious iron they got a saving of fuel. He thought that that might reasonably be expected.

Here, then, he thought, was one of the causes for this wonderful saving of fuel—that the Americans were working with pig iron low in silicon. They did not use up the carbon to reduce the silicon, and they probably made an iron which contained really less carbon than the English. This was a point on which unfortunately the hands of Englishmen were somewhat tied, because their engineers, when they went into the works, did like to see No. 1 pig with plenty of graphite in it. If they came across a pig iron which was approaching at all to white, they looked very askance at it, and immediately wondered whether bad steel was not being made. Therefore, to keep up the character of their steel, they had very often to go counter to their own idea of what produced the best economy. With regard to the rapid driving of the furnace, he thought this point was most important, because by rapid driving they saved at all points. But one of the difficulties that they experienced with rapid driving in England was that they got a greater consumption of fuel. He never could account for that; he had always been an advocate of rapid driving, but his difficulty was that he could not drive rapidly; the men would not be driven, the manager would not be driven, and the furnace would not be driven, because they had not got the plant, and could not get it. But he certainly believed that when the Americans had the advantage of being able to drive the furnace rapidly, they must necessarily drive it economically, and he was in favour of the practice which they had put forward. He thought himself that they must have great economy by this rapid driving. As regarded the life of the furnace, he believed in a short life and a merry one. He found that the saving of, say, 4 cwts. of coke to the ton of iron amounted to about £25,000 a year on this particular furnace; surely that was enough money to re-line the furnace two or three times over! But the saving of coke was not the whole thing; he thought there was a saving of wages as well. If, instead of the staff to manage four furnaces they got the same result from the staff for one, he was quite certain the cost of labour per ton would be lower. Therefore, he entirely agreed with the American practice; and if he had to put up furnaces himself, he would certainly rather put up one furnace to do the work than two, although the two might produce the same output; and he would do it even if the two furnaces could be put up at the cost of the one. After having considered all these points, he yet failed to see that the great advantage realised was due to the plant, the material, or the mode of working. He could not help thinking that this splendid result was mainly due to the wonderful spirit of emulation among the proprietors, the managers, and the men; and he, for one, would only be too glad, as an Englishman, if English managers, proprietors, and men could get contaminated with the same spirit, and he might add that he should be very pleased to carry the influence away with him.

Mr. **Julian Kennedy** (Pittsburgh) had had a few thoughts suggested to him by Mr. Gayley's paper. The first one was the great effect produced by very small, or apparently very small, changes in the lines of the furnace. In their original work, when they started out on this fast driving of furnaces—when the work was not really as good as it was now, but when they tried just as hard to get it so—their fast driving was not altogether due to the desire to drive fast. They very often tried a little slower driving, but found that the furnace would not work at a slower rate of speed, and they were therefore forced to drive as they did. He ascribed a great deal of this to the difference in the furnace lines compared with what they were now. Those differences were not very large, but still they had a great effect, as they had noticed in Mr. Gayley's paper. He found in the case of one furnace, when he tried to reduce the blast, that he came to a certain point, and then he could go no lower. Then, by making a very trifling change in the top of the furnace, he found he could by degrees reduce his blast 3000 cubic feet. He thought all through the paper they saw evidences of the great effect of very small changes in the lines. When they first started this modern system of driving, their idea was to use a very wide top, and they carried that to the extreme, to their own detriment. Their theory was that the proportion between bell and stock line should be geometrical, instead of arithmetical. Assuming a 7-foot bell to be correct for a 10½-foot stock-line, they assumed a 12-foot bell would be correct for an 18-foot stock-line, instead of 15, as would now be the practice. All through he thought the record showed that the lines of the furnace had a great deal to do with the work. He also thought that Mr. Gayley's blast furnace was probably helped a great deal by his system of blowing. Mr. Gayley was equipped with a very fine set of engines, which were regulated by an automatic governor, that could be set at a certain number of revolutions, and would keep up that number of revolutions whether the blast pressure was 16 lbs. or 6 lbs.; and if they were around the engine-house, they would never know the difference. With regard to the economical side of the question, it seemed to him that Mr. Gayley had got his coke now to a place that was undoubtedly very satisfactory, and it was doubtful whether it would ever be brought much lower. The labour, he supposed, was all as low as it could be in small furnaces aggregating the same production. The management in some departments must be less. A certain number of men were dispensed with, and if Mr. Gayley succeeded in getting an average life of 300,000 tons to a lining—which he had no doubt that he would do if he got a blast which he was not compelled to stop by labour troubles or some other extraneous causes—he did not see why Mr. Gayley's practice should not be as good in every respect as it would be with a multitude of small furnaces aggregating the same production.

Mr. WILLIAM WHITWELL said he rose at the call of the President to say a few practical words on their practice at Thornaby, in England. Nothing definite had been said during this discussion as to what was being done at the English works, so far as he had heard, and therefore he thought it might perhaps interest some of their English visitors to know what had been done without much pressure, and with a furnace very similar in lines to the one that had been so highly approved by the several speakers—No. 8. They were working at Thornaby a furnace 75 feet in height, and 18½ to 20 feet in diameter, with a bell of 10 feet 6 inches, and with a hearth of 10 feet, with six tuyeres. They did not use the large tuyeres, so successful in America, because up to the present time they had not found it advantageous to do so. Their tuyeres were about 4½, and occasionally touched 5 inches, when required. Their pressure of blast, on the other hand, did not exceed 5 lbs., as a rule, as the working pressure in the engine-house, which practically at the tuyeres meant about 4¾ lbs. They commenced many years ago with smaller furnaces, never more than 20 feet in diameter, and 60 feet in height. They were the first in the Cleveland district to use the rather larger cubical contents of furnace, and to some extent they were successful; but the additional height in the Cleveland district was the great element of success. It was arrived at perhaps more as an accident than otherwise, more with a desire to obtain additional cubical contents than putting in a new bottom to the furnace, and Mr. Vaughan in that respect deserved the congratulations of their own district, and perhaps of the world, because that was the first occasion when greatly cheapened production was obtained.

But to proceed with the hæmatite furnace. He had told them the dimensions. Their make was approximately from 700 to 800 tons per week. At the present time they were working in the fourth year of the furnace life at about 800 tons; and they were improving, doing better, and they anticipated still further improvement. But their ores were very different from the rich ores that they had heard described so vividly here. He should like to know very much, when the author of the paper came to reply, whether he would tell them if the general American practice coincided in any degree with what they had heard described by Mr. Gayley, or whether it was one particular individual furnace, working this particularly excellent ore from Lake Superior, and ores of a similar kind. The ore that they used in Cleveland did not average above 50 to 50¼ per cent. It contained mixtures of various kinds. They generally used seven or eight different kinds from Africa, Elba, and from Spain—north and south; and in mixing the ore they tried to arrive at the quality of pig that their customers required for the time being. They did not work so low in silicon as had been the practice in America, and with such advantage too; but they made a pig for Bessemer purposes which ran from 3 to 3½ per cent., and for the Siemens open-hearth furnaces from 2½ to 3 per cent.; and where customers required it they made it from 1½ to 2. They tried to keep their sulphur down. Their phosphorus generally ran a little below ·04, and they sometimes got it down to ·0275. Their practice was not as regular as that of people who were working for the Bessemer converter or open-hearth furnace, but they made what their customers required—iron for shipment for the Continent of one quality, and iron for local consumption of another. They changed sometimes from one week to another, just as was required; but still, with all that, they managed to get something like 800 tons.

Now as to their coke, the average consumption would run for the last two years, and was now running, at something like 19 cwt. per ton of iron, with this 50 per cent. ore. The limestone that they used was the carboniferous limestone from their own district, and they used 6⅛ to 6¼ cwt. In that respect they used very much less than was used in America for the richer ores. He was a good deal inclined to think that they might work more advantageously by keeping their furnaces more open, and getting rid of their sulphur more successfully than they were doing if they were to use more limestone; and that was a hint they had got. The average silica in their ore was about 6¾ to 7 per cent.; and if they got that, and worked with that regularly, they got pretty equable results. The ore came in, cargo after cargo, and in any work of that description changes were to be reprehended and avoided. The best ores were undoubtedly the most economical to smelt.

There was just one other point that he should like to mention, and that was as to the ores from the north of the Gulf of Bothnia, of which they had used something like 8000 to 10,000 tons a year. That ore, owing to the stoppage of the company, was practically no more available, and the last few cargoes were coming in at the present time. If the company went on to secure a future success for this ore, and if they could only confine themselves to a purely silicate ore, they could have nothing better to work with, as that would approximate very closely to Lake Superior ore. On the other hand, there was a great deal of apatite here and there in it, and this was shown by the rather light colour. Veins of phosphate of lime ran through the stones, which enabled them to select it with ease; and the inferior ore might be used for ordinary purposes with very great advantage, for it was an excellent ore. In regard to the pressure of the blast, he was inclined to think they must suit themselves in their driving, and use what pressure was economical with each. If they wanted their furnaces to run on shorter time, if they were willing to lose something in the quantity of coke consumed, they might use rather more and drive harder; but if they could get their furnace to drive on a certain burthen, he believed that was one point that they ought to look to. They were apt sometimes to put on pressure and drive their furnaces down. That simply meant lowering the quality and rising in sulphur—two decidedly objectionable features, which they always ought to struggle against. One important point for the meeting to consider was this. They in Cleveland changed their heats when their furnaces got too hot rather than burn their iron. In America they never changed their heats, he believed, in the best practice. Again, in Cleveland they worked by pressure. The Americans worked regularly, he believed, by the revolutions of the engine, and they always kept up the pressure, and did not lessen the production of the furnace to keep up the quality, as they in Cleveland did. In those two respects there was something to be learned. Now, how did the Americans do it? They had an individual engine to each furnace, as a rule, in the best practice. They had not three or four engines working into the same main, and so contributing the common pressure to the one furnace, but they had an individual furnace, and fed it with the food most convenient for it, and if it could take more, they gave it. They did not check the pressure, as they had an engine to work for each individual furnace. If America could give them the same material, with their beautiful Durham coke, the best of which ran from about 5 to 7 per cent., he believed they could show the Americans different results. But with the material they had, and under existing circumstances, he thought that their growth would have to be gradual. He should be glad to know, as he said before, whether it was these individual furnaces, using half a million or three-quarters of a million tons of the best ore, that worked the best, or whether those using imported ore from Spain or Africa were getting anything like approximate results.

Now, what was the English practice? Their practice was to make the most money, or, in some circumstances, to make the least loss, because it was not always profitable to make iron in England; and if they could keep a furnace going for a long time without checking it for repairs, they thought it was of advantage. As working now, they expected to make something like 475,000 to 500,000 tons of pig iron from one lining in twelve years. If they did that, they were perfectly willing to re-line. They could not re-line as they did in America. Everything done in America in the shape of repairs or building seemed to be much more rapidly done than they had any experience of in England. He did not understand it. He heard of the Americans re-lining a furnace (and drying fourteen days too) in seven weeks. If in England they re-lined a furnace in three months they thought they had done exceedingly well. How they did it in America, whether their labour was more under command, whether their labour was more energetic, or whether there was competition in the labour, he did not understand; but they had something to learn in that respect. Now they simply put their money in their furnace, and perhaps expected to build two or three furnaces for the same amount that the Americans spent on their one furnace and on plant. The Americans had great provision in heating-power, no doubt, but not so much as was given in the Cleveland district. The American practice was to have three large stoves to one furnace with this large production, and therefore they did not work up, perhaps, to the same heat as in the Cleveland district. These were points, as he said before, for individual practice. They would go and see these furnaces throughout the district with intense interest, and undoubtedly they would get all the information they possibly could, and go home and digest it. He believed that the more they heard, the better they should be able to arrive at a conclusion as to what was the best for them to do under existing circumstances, but at present they were speaking off book, and simply from the information they had received from time to time. In looking back over many years, it was interesting to visitors to see the enormous increase in production in America. They congratulated their hosts heartily upon it. They were all striving for the same result, but he was inclined to think that some of the Americans were going much more rapidly than their visitors. Whether they should ever be competitors with them in the markets of the world depended entirely upon themselves. That was an economic question which he should not allude to further. All he would say was this, that he believed that there was room enough, as the President had said in his admirable address, for all of them; and he desired in conclusion to congratulate the writer of that excellent paper, and to particularly thank those American gentlemen who had elucidated the matter so very clearly.

Mr. WM. KENT (New York), who illustrated his remarks by Plate IX., said he had tried to make a study of Mr. Gayley's paper by the ordinary method of a diagram, which he would pin up so that they could look at it. As he interpreted Mr. Gayley's table of figures on page 36, there were three columns which represented results or effects. They were the "average daily output" of the furnace; the "average coke consumption" of the furnace; and the "capacity in cubic feet of the furnace for one ton of iron production per day." He had plotted the upper three lines on his diagram as the results. The red line on the diagram gave the product of pig iron per day. Beginning with the Isabella Furnace in 1876 at 76 tons per day, and rising with the furnace in figure 8 of Mr. Gayley's paper in 1889 to 310 tons per day, they would see that the increased production followed a pretty uniform and steady law of rise. The upper line in the diagram represented the coke consumption, beginning at 3000 lbs., and declining somewhat irregularly to 1920 lbs. The cubical capacity of the furnace for one ton of iron per day, beginning at 197 cubic feet, decreased very rapidly in that remarkable little Escanaba furnace (the furnace "A" of the Edgar-Thomson works which Mr. Gayley described), down to 90 cubic feet; then going to 135 cubic feet; and then decreasing steadily to 59 cubic feet, the present amount of capacity; and, as Mr. Cook told them yesterday, that low figure had been reduced even in the anthracite regions. Those were the three results. They studied the paper and the table to find the causes or the results; and in the table they had two columns in which they might or might not find the causes: first, the cubical capacity of the furnaces; second, the volume of air blown into the furnace. The lower red line on the diagram represented the cubical capacity, beginning at 15,000 feet (the little furnace, of course, went outside the diagram), and then went down to 6000 feet. Then it came up again to 17,000 feet, and then ran along very irregularly to the present limit of 18,200 feet. The difference between the fourth furnace and the tenth furnace in the list was nearly 400 cubic feet capacity, showing that the cubical capacity of the furnace was nearly a constant quantity. The volume of air was very irregular.

He would ask any one to study that diagram, and see if they could find any relation between the cubical capacity of the furnaces and the volume of air pumped into the furnaces, or a ratio between these two quantities, considering those two quantities as causes, and those other three lines as effects. He could find no such relation. If they said that rapid driving increased production and increased economy, then, taking out certain figures, he could show them also that the opposite causes would produce the same results; that rapid driving produced economy, and that slow driving produced economy; that large capacity gave economy, and that small capacity gave greater economy, and *vice versâ*; and so with every other way that they could put it. So that the mere question of the volume of air pumped into the furnace, and of the cubical capacity of the furnace, were not the controlling causes in giving them low consumption of fuel and high production of pig iron. He did not pretend to say what the cause was. He thought that it was very obscure, and one that had yet to be studied. Mr. Kennedy had touched on one cause—the lines of the furnace. That was a very important matter. He thought they would also find that the physical and mechanical properties of the ore and of the coke were very important conditions. The distribution of the materials in the furnace, the method of charging, and—what they could not tell about—the inside of the furnace (because they could not get inside of it while working), the character of the materials in the various zones of the furnace, and especially in the zones beginning with the fusion; and whether the materials at the proper heat for reduction were pulverulent, or were decrepitated into powder, or were in small pieces, allowing the gas to come up freely through them, or whether they were agglutinated together in a pasty mass, preventing the gas from going through —all these, he thought, had a most important effect on the economy of production, although they were too obscure for them to find out at present.

As Mr. Kennedy had said, there were important indications in Mr. Gayley's paper that a change of lines had much to do with economy. There was another thing in the paper which showed that, while a furnace was in blast, or in the condition of a furnace oven, with all the methods of driving and everything else the same, then, owing to some temporary stoppage, or to some accident, the furnace suddenly changed its rate of working, and reduced its production, and that, too, when there was no other change at all; so that they could not discover until they blew out the furnace what was the matter, and then they found that there had been a slip, or that something had been going wrong inside of the furnace; the cause then appearing seemed to be a defect in the furnace lines, or in the mechanical condition of the mass of material inside the furnace. He would say, for Mr. Whitwell's benefit, in reply to the question whether this was an exceptional case that had been presented, that the Lake Superior ores were about one-half of the total ore consumption in the United States, and that all the furnaces running on Lake Superior ores and Connellsville coke approximated very closely to that practice, wherever they were provided with proper equipment, engines, boilers, and ovens. The Lake Superior ore and Connellsville coke, moreover, while they were a very important factor in the economy of production, and in capacity of production, were still not the all-important factors, because they would find in Tennessee and in Alabama, on much poorer ores and much poorer fuel, that remarkably large yields were produced, although not equal to those obtained in that locality.

Mr. J. D. **Weeks** (Pittsburgh) said Mr. Whitwell had asked the question whether that practice was confined to the Lake Superior ores and to this coke. He regretted exceedingly that he had not with him a report of some practice at the Ivanhoe Furnace, in Virginia, which showed, with a small furnace, and on ore giving a low percentage of metallic iron, with the Pocahontas flat-top coke of Virginia, he thought, as good results, all things considered, as were shown in Mr. Gayley's paper. The Ivanhoe Furnace was a furnace only 12½ feet in the boshes, and it was some 60 feet high. The ore mixture in the furnace yielded about 47 per cent. One portion of it was Pottsdam ore, and the other portion was limestone ore, with very little lime in it, however. The ores were from limestone measures which had been washed, so that the stock went into the furnace in a washed condition. Considerable water came from the washing in connection with it. The Pocahontas flat-top coke was a coke very low in ash—containing somewhere about 5 per cent.—and it came from a coal that had but a small amount of volatile matter in it—only some 18 per cent., he thought, before it was coked. That small furnace, with 12½ feet bosh, had been run for the last six or eight weeks, producing about 68 tons of iron per day, on a fuel consumption, with those ores, of but little over 2000 lbs. of coke to 2268 lbs. of iron, and it seemed to him that, with the character of ore that they had there, that was an exceedingly good result. If it was desired, he would have the full details of that practice worked out, and, together with the lines of the furnace, given to the Institute.* There was one thing more that he had hardly understood in the discussion. He had noticed that the only comparisons that had been made between the cokes had been chemical. They had compared the Connellsville fuel with the Durham fuel simply by percentages of ash. Now, he thought that he was right in saying, that while the purity of fuel was one thing, the physical characteristics of coke, within certain limits, at least, were of a great deal more importance than even the chemical constituents. He thought that possibly in some of those physical characteristics the Pocahontas flat-top coke was not quite so good a coke, though lower in ash, than the Connellsville coke. It did not have that coating of graphitic paint on it which seemed to him one of the most important things in connection with the working of blast furnaces with their cokes. It seemed that that coating of graphitic paint that they had seen in that country to be common, did not give them hot-tops in their furnaces, and in the absence of that silvery lustre which nothing but a coating of graphitic paint could give—a fire-proof coating—they did not seem to have hot-tops and greater fuel consumption than they ought to have with coke with even a lower percentage of ash than they should have, or at least than they then had, in the cokes which had a higher percentage of ash. He had been hoping that their friend, Sir Lowthian Bell, would tell them how it came about that a coke of inferior composition as to ash—that was, with a higher ash—would give better results in a furnace than a coke with a lower ash.

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* The details had not come to hand up to the time of going to press.

Sir **Lowthian Bell** said he would just like to say, in answer to the question which had been addressed to him with regard to the nature of coke, that the chemical composition alone afforded only an imperfect explanation of the value of coke as a fuel in the blast furnace. Upon what the value depended he could not tell them, but this he knew, that different kinds of coke were more or less easily acted upon by hot carbonic acid. Now, in the event of that action going on in the upper part of the furnace (which was the only position where carbonic acid in any quantity was to be found), the coke there was oxidised by the carbonic acid. The effect of this was that two units of carbon escaped as carbonic oxide, evolving together 4800 calories instead of the 8000 generated by the one unit of carbon had it left the furnace as carbonic acid. By this reaction there ensued a loss of 3200 units; but this was not all. The second unit of carbon thus gasified in the reducing zone never reached the tuyeres, and for all useful purposes in the furnace was so much loss. Now, experimentally he had determined that hard semi-metallic looking coke, generally speaking, was better able to resist the solvent power of carbonic acid in the reducing zone than coke of a softer and more porous character.

Mr. **Edward Martin**, Dowlais, said he had had some experience in coke-making. Sometime ago, when he first took the management at Dowlais, they were making a large quantity of coke in ordinary ovens, and without a very good system of washing. That coke was soft, but fairly bright, and worked with a very bad yield in the furnaces. In fact, it was used with difficulty. The same fuel, thoroughly washed in a Coppée washing-machine, and thoroughly coked in Coppée ovens, was now doing work equal to the best coke made in the district; and, though its appearance was not at all of an inviting character, he did not think that much depended upon whether the coke was lustrous or otherwise, provided it was hard, dense, and low in ash.

The **President** said he thought they would agree that it was difficult to exaggerate the value and importance of the paper which Mr. Gayley had submitted to them. It was a very excellent record of the skill, knowledge, and energy with which their American cousins conducted their pig iron manufacture; therefore, they would concur with him in acknowledging that their warmest thanks were due to Mr. Gayley for his admirable paper, and he would ask them to give expression to their thanks, and tender them by acclamation.

Mr. **Gayley** said, in reply, that the interest which had been manifested in the paper that he had presented was a matter of deep gratification to him, and he was sure that the discussion which had taken place would be of much value to all. On account of the extent of the discussion, he would make but a very few remarks. He would first allude to the shape of the furnace. That was a matter that had been brought up in discussion. The furnaces shown in the drawings represented simply types of furnaces. They had but three furnaces when they first started to make these comparisons; afterwards five, and now they had nine. Their general practice had been to decide on one type of furnace, and then to carry that type throughout the whole line. It had been stated by Mr. Windsor Richards that the future development of American furnaces would probably be in the direction of larger capacities; but their more recent experience at the Edgar-Thomson works had been just the reverse. They found that they got a larger output and a lower fuel economy by narrowing their furnace stacks, as they would see by reference to the last furnace that he mentioned, where the cubical capacity had been reduced from 19,800 cubic feet to 18,200 cubic feet, with a larger output and a decrease in the consumption of coke. The tendency was therefore in the direction of narrow stacks, and he thoroughly agreed with the idea that had been presented as to the angle of the bosh, as that which he had found in his practice to give the best results was 75°. With regard to the quality of the ores, he did not know that they had any data showing the relative reducibility of the Lake Superior ore and of the Cleveland ores; but that was a matter which they were now taking up, and he hoped at some time in the near future to be able to present results on that point.

There was one point in particular in their practice with regard to ores that he wished to emphasise. They used at the Edgar-Thomson works probably eighteen different kinds of ore, and they had a great variety, as they saw, to select from. Now, in a furnace making regularly Bessemer iron, they aimed at selecting from those piles of ore such kinds as they had demonstrated by actual practice to give better results when worked together, and their more recent practice showed that they were getting far better results by discarding the lump ore and using exclusively fine ore. By fine ore he would also include those ores obtained from Lake Superior which had a shaly structure. He would also emphasise the selection of coke. They endeavoured, as far as possible, to get their coke from a mine where the quality was as uniform in appearance as possible, paying no attention to the chemical analysis, but selecting the hard and silvery coke, and avoiding as much as possible the softer coke, which, as had been explained by Sir Lowthian Bell, was found to waste away at the top of the furnace. They found the peculiar circumstance there, that during wet weather, or during days when there was a great deal of moisture in the atmosphere, the quality of coke that they obtained did not give them the same duty in the furnace as that made in cold crispy weather. There was less density, it was very much softer, and it crumbled up to a greater extent. He had also found that where a great variety of coke was used from a great many different mines, they got far poorer results than when they made a selection from one or two. He would conclude by saying that every point in the details of the management of their blast furnaces was emphasised. There was no point, no matter however insignificant it might appear, but which was treated as if it were a matter of vital importance. And in addition to that, they had also derived no little benefit from putting in practice the many valuable suggestions obtained through the laborious work of Sir Lowthian Bell, whose investigations had lifted the manufacture of pig iron out of the rut of a rule-of-thumb practice, and placed it on a substantial scientific basis.

CORRESPONDENCE.

Mr. **Fred. W. Gordon** (Philadelphia): Mr. Gayley's paper calls our attention to the very expensive blunder hitherto made in blowing too much wind into a given size of furnace.

It was quite evident from an analysis of blast furnace operations that the work we are doing in America is anything but creditable. We were consuming fully 1000 lbs. of coke more than is necessary for each ton of iron made, and were hammering the linings of our furnaces out in a very short time; and nothing but the very high price of pig iron would stand the drain.

It had long been my pet scheme to gradually reduce the quantity of air, at the same time increasing the burden to the maximum and decreasing the limestone, and determining if possible the fuel economy which might be reached consistently with the maximum production of the furnace.

After the success of the Isabella Furnace at Pittsburgh, which was remodelled in 1880, the North Chicago Rolling Mill Company had their furnaces re-lined under my instructions, the bosh being decreased from 21 to 20 feet, the hearth increased from 9 to 11 feet, and an angle of 80° to the boshes substituted for one of 75°. The bell was made 11 feet for a top of 15 feet 4 inches. There was then no practical difference between the Isabella and the South Chicago furnaces.

The result at South Chicago fully justified my anticipations. It gave us the starting-point from which to observe what was the most desirable volume of blast. It appeared that this quantity had some relation to the area of the hearth—the most natural thing to base it upon. As, however, there is such a vast difference in the efficiency of blowing-engines, the tightness of the conduits from the engine to the furnace, and the amount of carbon consumed directly by the oxygen of the ores rather than by the blast, the actual revolutions of the engine made but a poor measurement at the best, so that the fuel consumption, which seemed to be a better standard of comparison, was adopted.

During the winter of 1885 and 1886 I was employed as engineer at the Joliet Steelworks, Joliet, Illinois, to remodel their furnaces and obtain a fuel economy of less than 2000 lbs. of coke to the ton of iron. This was accomplished by re-lining their 20 × 80 ft. furnaces, making the top 16 feet, and putting in 12-ft. bells. With these improvements, a product of about 260 tons of iron per day was obtained, equal to 61 cubic feet per ton in twenty-four hours.

In the following summer the same work was undertaken at the Cleveland Rolling Mill Company's Furnace, and 210 tons of iron per day was obtained from a 20 × 75 ft. furnace, on a fuel consumption of less than 2000 lbs. per ton of iron. This furnace was altered by simply banking down, and changing the diameter of the bell from 10 feet to 12 feet 6 inches, the top being 16 feet 7 inches.

In 1885 a furnace at Steubenville, Ohio, only 14 feet bosh and 58 feet high, with a 10-ft. top, 7-ft. bell, and 8-ft. hearth, was blown in, and about 650 tons per week was obtained on a fuel consumption of a little over 2000 lbs. per ton.

All these furnaces were operated on practically the same materials as those used by Mr. Gayley, namely, Lake ores, or their equivalent in foreign ores, and Connellsville coke.

I was very careful in the above and other similar work to employ the minimum of blast, and to very slowly increase it until the maximum seemed to be reached, or where the driving of the furnace seemed to affect the grade of the iron or the fuel consumption.

Even a marked change in the furnace was not considered sufficient cause to abandon our line of action, for having applied a certain quantity of blast to a certain burden, it was continued until its effect was established in the furnace. It often happened that even with slight changes apparently great disturbances were produced; but they were only temporary, and it was evident that no information would be obtained, and no permanent good results arrived at, if a policy was not followed in spite of all seeming indications that we were in error.

Summing up the result of these and the other operations, it appeared to me that the best measurement for the quantity of blast was the consumption of 5000 lbs. of fuel per day per square foot of the sectional area of the hearth.

As these hearths were constructed in very much the same way, having about the same projection and number of tuyeres, it was fair to assume the area for comparison as the area of the brickwork when it was first laid.

Again, at furnace "C" and the "Jupiter" furnace at St. Louis, operated by the Western Steel Company, these furnaces were blown in and the same policy was adopted as in the above instances. In this case we had Pilot Knob ore, containing an average of 23 per cent. of silica, of which two-thirds was used, the balance being Iron Mountain washed, a very good and very pure ore, and South-West, also a fine ore, and working freely in the furnace, the mixture containing from 18 to 19 per cent. of silica. This was smelted partly with Illinois coal in its raw state (as high as one-third by weight was used), and partly with Connellsville, Pocohontas, New River, and Walston cokes. No regular supply of fuel could be had, on account of the disturbed condition of the labour market, and the incapacity of the railroads. Those familiar with the fuels named will note the great variety of their structure and composition, and when we smelted this highly silicious mixture with these fuels, we were undertaking no small problem. Yet the result was satisfactory, seeing that, from an 18-foot furnace, 75 feet high, we produced 140 tons of No. 1 Bessemer iron per day on a fuel consumption of 2100 lbs.—that is, when raw coal was used, estimating a pound of coke as equal to two pounds of coal.

The next experience of importance which I may recite was obtained at the blowing in of the first furnace at Ensley, Alabama. This plant has four furnaces, 20 × 80 feet, hearth 11 feet, top 16 feet, with a 12-ft. bell; angle of bosh, 80°. I gave a detailed account of the blowing in of this furnace in Volume xvii. of the "Proceedings of the American Institute of Mining Engineers." The ores contained about 46 per cent. of metallic iron, and the coke consumption per ton of iron was 2240 lbs., with a product of 165 tons per day.

Adding the fuel consumption of these several furnaces, together, with a number of others too tedious to mention, wherein quite a variety of material was used, the average was 4247 lbs. per foot of sectional area of the hearth per twenty-four hours, the extremes being 5200 and 3440 lbs.

If the text of Mr. Gayley's paper is correct in stating that a 22-ft. furnace had an 11-ft. hearth, the coke consumption in his case amounted to about 6000 pounds per square foot, or nearly 50 per cent. more than the above average.

No absolute rule can, of course, be adopted in this, any more than in other furnace practice, though I believe that something near the average might be arrived at by comparisons of a great range of furnaces, when doing their very best work, and it seems that it is an important question to consider.

The old question of the temperature of the blast has been very exhaustively discussed from time to time. The inference seems natural that if heat carried in by the blast may be substituted for heat produced in the furnace by fuel combustion up to a certain temperature of blast for a given ore and fuel, each calorie then introduced may supplant that amount of fuel which would have generated a like quantity of heat in the said furnace.

The ratio of CO to CO_2 in the temperature of the escaping gases being the measure of the heat utilisation in the furnace, the blast temperature (while within practical limits) should be increased until the percentage of CO_2 falls, or the temperature of the gases unduly increases.

In my practice, I have invariably employed the highest blast temperature that could be maintained, with a reasonable degree of regularity, and have never found a case where a reduction in the blast temperature would improve the condition of the escaping gases, either in composition or temperature. Hence I believe the limit has not been reached for the highest fuel economy.

If as desirable a gas can be obtained in cold blast furnace practice as when the blast is heated to 1600° Fahr., and *vice versâ*, I think the proposition is proved; but I have found that the lower the blast temperature, the more difficult it was to get, and where atmospheric temperatures are employed, only selected ores, flux, and fuel will give the result, and that selection has a very narrow range indeed.

A small charcoal furnace was remodelled to my drawings as follows:—Total height, 60 feet; diameter of bosh, 7 feet 7 inches; hearth, 3 feet; top, 5 feet; bell, 3 feet, the furnace being blown with one tuyere. There was no semblance of a hot blast. The ore used was a mixture of brown hæmatite, averaging 50 per cent.; limestone, as pure $CoCo_2$ as could be obtained; the fuel was charcoal, with an average of 85 per cent. of carbon (the balance being mainly moisture). A burden of 1120 lbs. of this ore was carried on 600 lbs. of charcoal, and a product of 15 tons of Nos. 1 and 2 car-wheel iron per day was obtained.

This result will come out as well as any furnace-work I have any record of, either cold or hot blast, for the utilisation of the fuel in the furnace. It was, however, only after repeated trials with many mixtures that such a result was reached. A slight increase of alumina or magnesia, or a change of the character of the ores, though giving almost the same flux, reduced the grade. The furnace could not be safely kept on this burden, while hot blast furnaces have been kept steadily on a burden equal to this, *plus* that which could be carried by the blast heat.

Again, though it is heresy to say it, the heat of the blast has no influence on the percentage of silicon. Given an ore mixture, a limestone, and a fuel, and the lowest percentage of silicon that can be reached with cold blast may be slightly reduced by increasing the blast temperature. Not that the blast temperature has any other effect than that the amount of silica present due to the ash of the fuel is reduced by the reduction of the fuel itself to the iron made. It is, however, easier to increase the silicon when using highly heated blast, and only good burdening will keep it under control.

My experience at St. Louis, when smelting the mixture above referred to, carrying 18 per cent. of silica, with New River and Pocohontas coke, containing about 5 per cent. of ash, and only 2 to 2½ per cent. of silica—having the slag as high as 40 per cent. in silica—was that the silicon would average too low through the grain of the pig, and the sulphur was all that could be desired in a No. 1 Bessemer iron. The high price of coke (some $6·50 per net ton) made the fuel economy so important a consideration, that iron higher in silicon was purchased, while the heavy burdening with the low silicon was continued. Mr. Charles Stewart, general manager, informed me that when the Connellsville coke was obtained in quantity, the silicon was much more at his command. There a small percentage of silica in the fuel governed the silicon in the iron, while the effect of heating the blast some 1600° Fahr. could be neutralised by an increase of burden.

My own and Mr. Edward Dowd's experience at Sheffield, Alabama, with Pocohontas coke has convinced both of us that with pure fuel, ores high in silica can be used to produce No. 1 iron with very low average silicon, no matter how high the temperature of the blast may be.

With these facts, and this sort of reasoning, I fancy that had Mr. Gayley employed 1500° Fahr. instead of 1100°, he might have exceeded his excellent record.

Mr. JOHN BIRKINBINE (Philadelphia) remarks that the data presented by Mr. Gayley in his paper, and that brought out in the discussion, illustrated the practice of some of the more important American blast furnace plants, and while the figures given had assumed proportions which, as mentioned by Sir Lowthian Bell, were surprising, they were not relatively more so than some of the results obtained in the smaller furnaces of the United States. A record made of the average work of the American blast furnaces would fall far below that given by Mr. Gayley; but if the figures he offered were compared according to the cubical capacity of the furnace, and if due allowance was made for ores, fuel, temperature of blast, &c., some of the smaller furnaces would be found as well up in the race. The demands made upon American blast furnace managers had been such as to develop characteristics in some who were operating those blast furnaces that had done more than anything else to bring them prominently to the head of the profession, and, in discussing Mr. Gayley's paper, Mr. Birkinbine would confine his remarks to two features, namely:—

1st, The remarkable output and low fuel consumption obtained in some of the smaller blast furnaces, particularly in those using charcoal as fuel.

2nd, The personal factor of management, which, after all, is the true secret of the remarkable and unusual records which had been presented in Mr. Gayley's paper and in the discussion.

Few American blast furnaces, using charcoal as fuel, reached the dimensions of the smaller furnaces using coke. The largest charcoal furnace in the United States had a diameter of bosh of 14 feet and a height of 60 feet; the next in size had a bosh 12 feet in diameter and a height of 65 feet. An average size of the blast furnaces now active which used charcoal as fuel would show a bosh diameter of 10 and 11 feet and a height of 50 feet. Iron pipe stoves, as a rule, were in use, but fire-brick stoves were connected with four or five plants, and a few furnaces were still operated with cold blast.

Without burdening the discussion with data obtained from numerous blast furnaces, the results secured at two of the blast furnaces using charcoal as fuel were presented.

The first of these was the record of nine years' operation of the Spring Lake Furnace, located on the eastern peninsula of Michigan. This furnace had a stack 46 feet high, with a bosh 10 feet 6 inches in diameter, having a crucible 5 feet in diameter, and a bell of 5 feet. It was blown by a vertical engine, with air cylinder 5 feet in diameter, and a 4 foot-stroke. The blast was heated in iron pipe stoves to 850° Fahr., and entered the furnace through four 3½ inch tuyeres. The average yield of the ore mixture, which was chiefly soft hæmatites from the Lake Superior region, was from 58 to 61 per cent. This furnace was first started on March 4, 1880, and up to September 1889, a total period of 3471 days, the furnace had operated 3205 days, or about 8¾ years. Complete data subsequent to September 1889 was not now at hand, but the following table would illustrate the duration of the different campaigns, and the results obtained in each.

The iron was weighed from the furnace at 2260 lbs. to the ton. The charcoal was charged by measure, 2748 cubic inches to the bushel, the weight averging 20 lbs. To this table, as presented by Mr. J. C. Ford (the manager), Mr. Birkinbine had added the calculated weight of charcoal per ton of iron.

	Total Days.	Stops.	Net Days.	Gross Tons of Pig Iron Made.	Tons of Pig Iron per Day.	Bushels of Charcoal per Ton of Iron.	Weight of Charcoal per Ton of Iron. —Pounds.
1st blast . .	677	7	670	29,040	43	94	1,880
2nd blast . .	799	7	792	33,124	42	95	1,900
3rd blast . .	331	11	320	15,279	48	89	1,780
4th blast . .	510	14	496	26,868	54	88	1,760
5th blast . .	586	10	576	29,237	51	92	1,840
6th blast . .	361	10	351	20,451	58	95	1,900
Totals and averages	3,264	59	3,205	153,999	48	92·4	1,848

This table showed that there was an average product of 48 gross tons per day, and a total consumption of 92·4 bushels or 1848 lbs. of charcoal per ton of iron made. In the first year of its operation, this furnace made, for one week, a ton of pig iron on 1715 lbs. of charcoal.

The second example was the Hinkle Furnace, located at Ashland, Wisconsin, on Lake Superior, using entirely soft red hæmatite from the Gogebic range. The furnace is 60 feet high, with a bosh diameter of 12 feet, and was equipped with two fire-brick stoves 18 × 60 feet, and a vertical engine with a 6-feet blowing cylinder and 4-ft. stroke. Mr. Morris R. Hunt (manager of the Company) had supplied the following information:—

"The furnace was first blown in April 4, 1888, and blown out June 30, 1888. During this time it made 3261 gross tons of pig iron. The actual days working were 73, and average daily output of 44·67 gross tons of pig iron.

"It was again blown in August 21, 1888, and blown out August 1, 1889. During this period, under Mr. Hunt's management, it made 26,137 gross tons of pig iron. The actual days of work numbered 316, and the average daily make was 82·71 gross tons of pig iron.

"The furnace was again blown in September 9, 1889, and in the interval of 14½ months just passed presented the following remarkable record:—

Total length of campaign	443 days.
Actual running time	382 days.
Total output of blast	41,600 gross tons.
An average of	109 tons per day actual running time.
The yield of ore was	55 per cent. iron.
The average consumption of charcoal per ton of iron	1815 lbs.
The average consumption of limestone per ton of iron	177 lbs.
The cubic capacity of the furnace is	3500 cubic feet.

6500 cubic feet of air per minute was blown into it through six 5-inch tuyeres at a pressure of about 5½ lbs., and a temperature of about 1300°. The best week's work was made during the visit of the Institute to the United States, when 1009 tons of iron were produced on an average fuel consumption of 1806 lbs. of charcoal. During that week the ores yielded 56·4 per cent.

of iron, and 9300 cubic feet of air at a temperature of 1300° was blown into the furnace. The limestone burden was 4½ per cent. of the ore burden. The composition of the cinder at the Ashland Furnace is reported as varying from 46 to 51 per cent. of silica, and 11 to 15 per cent. of alumina."

In each of the different classes of blast furnaces—that was, in the furnaces using anthracite coal, coke, or charcoal—and in most of the iron-producing districts, a few furnace plants had attained prominence by reason of large outputs, or a low fuel consumption, or both, and some of the works using lean ores, or ores difficult to smelt, were doing almost as remarkable work as some of the others whose materials or facilities gave them advantages. It was not always that the finest-equipped plants achieved the best results; on the contrary, quite a number of the blast-furnace managers who had attained enviable reputations had furnaces with but moderate equipments, and the credit of unusual outputs or low fuel consumption seldom rested with the plants, which had, as legacies, descended from father to son. A majority of the blast furnaces which had brought credit to the pig iron industry of the United States were managed by well-educated men, who graduated from the office, the laboratory, or from some other department connected with the industry. A visit to the plants which had been most successful indicated a thoroughness of management, and a care as to detail, which was impressive, and convinced a stranger at once that there were good reasons for the results obtained. The factor of personal management as affecting the output and returns of a blast furnace was too often overlooked, and even when credit was given for it, the full importance of such management was not appreciated.

Constant vigilance, strict attention to details, and a thorough familiarity with all the various features of the plant were necessary, and, in addition, acquaintance with the chemical and physical characteristics of the materials for the furnace, as well as of the composition, structure, and suitableness of the product for the markets accessible, were pre-requisites of good furnace management. But the phenomenal results which had been obtained were largely traceable to a confidence born of a realisation of competence to handle the plant, together with prompt and aggressive action in emergencies.

Mr. W. HAWDON (Middlesbrough) writes that in Mr. Gayley's paper the temperature of the blast is stated to be 1200,° which would appear to many, in England, at any rate, to be low. But as Messrs. Siemens had within the last few years *corrected* their water pyrometer (which was generally taken as the standard in such matters) in such a manner that what formerly was shown as 1500° was now 1250° or thereabout, this 1200° was probably about the same temperature as was the practice at most of the best English works.

In manufacturing pig iron in Great Britain, they tried to obtain two results, viz., economy of fuel, and, consistently with that, large makes. English practice had been:—1st, Economy of fuel; 2nd, Production.

American practice had been:—1st, Large production; 2nd, Fuel economy. There seemed to be an economic limit in driving a furnace, which varied for some hitherto unexplained reason with different furnaces. Instance the last furnace on Mr. Gayley's list. It was something beyond any chemical phenomena, and appeared to be due to such a construction of furnace, and such favourable conditions of working, that the material was presented at the zone of fusion in a manner and condition that caused rapid fusion to take place. And Mr. Gayley seemed to have hit this off in the furnace which he had last described. In England they had furnaces very much on the same lines, doing excellent work.

Now, the average consumption of coke, leaving out the top item on the list, which appeared to be abnormal, was 2400 lbs. = 21½ cwt. of coke per ton of iron made.

Compare this with English practice, using Spanish ore of 50 per cent. iron, as against the Lake Superior ore of 63 per cent., used at Pittsburgh. It would take at least 1 to 1½ cwt. more coke to smelt this 50 per cent ore, or, taking Mr. Gayley's figures, it would take 21½ + 1 = 22½ cwt. of coke per ton, whilst in England 19 cwt. and even 18 cwt. was pretty general practice.

To make 2000 tons with one furnace in a week required the same number of blowing engines, boilers, and stoves as would be needed to make it in two furnaces; and therefore the only extra cost in plant would be, in the latter case, the actual furnace stack itself, costing about £5000, with gallery, &c.

By using the two furnaces to make 2000 tons per week, and saving 2s. 6d. per ton, they should save this amount in twenty-four weeks. He allowed the 1½d. extra for additional labour that would be required in the front of the furnace. There would also be a considerable saving in re-lining, which, with rapid driving, was a serious item. Therefore, judging by these figures, it had clearly paid English makers to use two furnaces rather than one.

Mr. JOHN M. HARTMANN calls attention to the work of a furnace belonging to the Franklin Iron Manufacturing Company of New York, working on fossiliferous hæmatite of the Clinton group, anthracite coal from Scranton, Pennsylvania, and Connellsville coke. The furnace, which has a cubical capacity of 6731 feet, and 10 tuyeres, 4½ inches diameter, 6 feet up from the hearth, has a water-cooled bosh and tuyere and crucible jackets. The hearth is 10 feet 6 inches diameter, and there is one cinder-notch 4 feet up from the hearth. The furnace is worked with two blowing engines and three firebrick stoves. One week's work in 1886 showed the following results:—

Fuel, one-third coke, per ton of pig	2,538 lbs.
Ore per ton of pig	5.091 „
Limestone per ton of pig	1,426 „
Blast per minute	13,514 cubic feet.
Temperature of blast	1,100° F.
Temperature of escaping gas	210° F.
Iron produced—No. 1, 342 tons; No. 2, 260 tons; No. 3, 12 tons	614 tons.
Cinder per ton of pig made	2,474 lbs.
Yield of ore	44 per cent.
Ratio of escaping gases by weight $\frac{CO_2}{CO}$ = ·938 cubic feet of air per minute.	
Per 1000 feet of contents	2,000 feet.

The furnace for the whole year 1889 gave the following results after re-lining:—

Fuel, one-third anthracite, two-thirds coke	3,091 lbs.
Ore	5,376 „
Limestone	1,485 „
Iron per week	583 tons.
Output—No. 1, 11,002; No. 2, 16,846; No. 3, 2,476	30,324 „
Average heat of blast	1,250° F.
Maximum heat of blast	1,350° F.
Average air per minute	16,000 cubic feet.
Maximum air per minute	18,100 „
Average pressure	9½ lbs.
Maximum pressure	11 „
Average yield of ore	41$\frac{6}{10}$ „
Air per minute per 1000 cubic feet of contents	2,277 cubic feet.
Maximum air per minute per 1000 cubic feet of contents	2,689 „

Mr. **James Gayley** writes to say that the question of the comparative reducibility of Cleveland ore and the Lake ores of America has often been touched on in comparing English and American blast-furnace practice, and as it has always figured as an uncertain factor in such comparisons, I have had some experiments made which throw light on the subject. The ores selected for the tests are the ones principally used in the mixtures at various works for the production of Bessemer iron. The experiments were conducted by Mr. Grammer in my laboratory, under precisely the same conditions, and with the same apparatus, &c., as are described in Sir Lowthian Bell's "Chemical Phenomena of Iron Smelting;" and, for the purpose of comparing with some definite experiments, it was decided to follow the conditions governing experiments 36, 37, &c., recorded on page 18 of that work. The quantity of CO passed through the apparatus was 63 litres in six hours; the temperature obtained was 780 to 790 degrees Fahr. The results are recorded below :—

Ore Number.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	Average.
Per cent. Fe in ore. .	66·0	58·8	62·4	62·6	68·8	61·0	65·5	67·4	62·0	64·6	61·6	62·2	63·9
Per cent. original ore moved . . .	48·0	46·4	41·4	40·2	38·7	31·7	29·5	29·4	23·1	14·7	12·7	10·3	30·5

From the preceding table it will be seen that the average removal of oxygen is 30·5 per cent. Comparing this with the results obtained by Sir L. Bell, as recorded on page 18, we find—

Exp. 36. Calcined Cleveland ore, containing 40 per cent. Fe.
Original oxygen removed, 37·3 per cent.
Exp. 37. Lancashire hematite, containing 66·6 per cent. Fe.
Original oxygen removed, 35·9 per cent.—

which shows that the average Lake ore in America is somewhat more refractory than either the Cleveland or the Lancashire ore. The ores above given are all used extensively, and are selected as representing an average mixture at many American blast furnaces.

THE BESSEMER GOLD MEDAL.

The PRESIDENT said that they had been much gratified to hear that Mr. Hewitt* had so far recovered as to be able to attend there that morning, and he thought it would be convenient then to make the presentation of the Bessemer gold medal to Mr. Hewitt, which had been postponed on the previous morning.

He had now the very pleasant duty to perform of presenting to the Honourable Abram S. Hewitt the Bessemer gold medal for distinguished services to the iron and steel trade. When that matter was brought under consideration in London, it was well known that, as Mr. Hewitt would be the first to acknowledge, there was more than one man in America entitled to that distinction, and upon whom they would gladly have conferred it. Mr. Hewitt had been long known to their distinguished members on the other side of the Atlantic as most active in the investigation of new methods of manufacture, and as one of the most enterprising metallurgists on that side of the Atlantic. They proposed to Mr. Hewitt that he should receive that gold medal; but he thought it was fitting, and also due to Mr. Hewitt, that he should state that he promptly declined to accept it. Mr. Hewitt declined in a manner which rendered it difficult to any but very persistent friends and very resolute Englishmen to refuse. When they heard that their American friends had conferred once more upon Mr. Hewitt the distinction of President of the American Institute of Mining Engineers, and particularly with reference to their contemplated visit, and when they heard that he had been elected unanimously to that position, they felt that their proposal had received the stamp of approval from that side.

Mr. Hewitt had long been known to many of them in England as an advocate of scientific education, and a report which he had made on the metallurgical products at the Paris Exposition in 1867 was one of the matters which drew very clearly and distinctly the attention of the English iron and steel trades to the necessity of further improvement in our technical education as to iron and steel; and it was one of the reasons which led ultimately to the foundation of the Iron and Steel Institute. The development of the ideas which Mr. Hewitt there investigated undoubtedly led their leading minds to the foundation of that Institute, and therefore it was only a debt of gratitude which they were paying when they presented to him that gold medal. Again, Mr. Hewitt's services to the iron and steel trades of America were very remarkable. If he might take up again the point which Mr. Carnegie gave him yesterday, that that was a year and that that was a country of "firsts," he should say that Mr. Hewitt's record was distinctly a record of "firsts;" for in 1856, very shortly after the announcement by Sir Henry Bessemer of his invention for the manufacture of steel at Cheltenham, Mr. Hewitt very quickly made his way across the Atlantic to investigate the principles and methods of this new process, and the result of those inquiries was that the first experimental Bessemer converter was erected at the works of Messrs. Cooper & Hewitt in 1856. In fact, he believed that, with the usual rapidity of Americans, within sixty days from that announcement, a Bessemer converter was working in the States. Of course it was to be understood that that was an experimental converter.

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* Mr. Hewitt had been too unwell to attend on the previous day.

Well, then, he found further that Mr. Hewitt was the first to build an open-hearth furnace in the United States. Mr. Hewitt was concerned with the Siemens patents, and his open-hearth furnaces were worked successfully, and still continued to work successfully. To Mr. Hewitt was therefore due the initiative of the introduction of that process. But, not content with that, on the announcement of Mr. Snelus's invention for improved basic linings, Mr. Hewitt took an interest in that invention, which was the first step which led him to be concerned with the Thomas-Gilchrist basic patents, and through his intervention that also was first introduced into the United States. He had given them a record which justified their distinguishing Mr. Hewitt, and also themselves, by enrolling him on the list of the recipients of the Bessemer medal. But of Mr. Hewitt as a man, in New York, it was not for him to speak. His integrity, his public spirit, his self-denial, were well known to them all, and he thought that he might rightly use towards Mr. Hewitt the words of one of their American writers, who said—

"You know him well; no need of praise,
Or bonfire from the windy hill,
To light to loftier paths and ways,
The world-worn man we honour still."

The **President** then handed the medal to Mr. Hewitt, and read the accompanying Diploma, as follows:—

"Iron and Steel Institute, established in 1869, under the presidency of His Grace the Duke of Devonshire. This is to certify that the Honourable Abram S. Hewitt, a member of the Institute, was, by the unanimous votes of the President and Council, awarded the Bessemer Gold Medal for services rendered in the development of the iron trade of the United States."

The Hon. **Abram S. Hewitt** replied as follows:—Mr. President, no one can be more sensible than I am of the great honour conferred by the bestowal of the Bessemer medal, or more grateful for the felicitous and generous words in which you have given expression to the decision of the Council. Nevertheless, I am not able to accept this distinction, the great object of ambition in our profession, without a feeling of compunction, which justifies me in referring to the fact, that when the decision was made known to me, I asked the Council to reconsider its determination, and confer the honour upon some one who had contributed directly to the improvement of the processes which have brought the production of steel to its present state of perfection in this country. My own connection with the business, although lifelong, has been rather in the direction of administration, of the study of the economic conditions of the trade, and of legislation affecting its interests, than with technical details. I can make no pretensions to either the scientific or the practical knowledge which constituted the merit of the eminent men whom you have heretofore decorated with the Bessemer medal. Nevertheless, I am somewhat reconciled to your decision by the information that this particular medal is conferred out of the ordinary course, and has been provided by Sir Henry Bessemer in view of your visit to this country, in order to enable you to make a recognition of the wonderful development of the steel industry which has taken place during the last decade in the United States. Receiving it, as I do, with a profound sense of the honour which its possession implies, I feel that I hold it in trust, as it were, for the able engineers who have had to deal with the new processes for the manufacture of steel, and of whom you have seen fit to select me as the representative.

In one respect, however, I may have been sufficiently in advance of my associates to attract your favourable consideration. Mr. Bessemer read his celebrated paper describing the process of producing steel without fuel at the Cheltenham meeting of the British Association for the Advancement of Science in the summer of 1856. An imperfect report of this paper was published in the journals of the day, and attracted my notice. The theory announced seemed to be entirely sound, and the apparatus simple and effective. I gave orders at once, without further information than that derived from the published report, to erect an experimental vessel for the purpose of testing the possibility of producing steel direct from the pig iron. In the same year in which the paper was read, the experiment was tried at the furnace of Cooper & Hewitt at Phillipsburg, in New Jersey, and the result served to show beyond all doubt that the invention of Mr. Bessemer was one which could be successfully reduced to practice. The same difficulties, however, which confronted him showed themselves in this humble experiment, and the further prosecution of the matter was deferred to a more convenient season. We all know the obstacles which Mr. Bessemer succeeded in overcoming, and the marvellous ingenuity and wide range of knowledge which he brought to bear in perfecting his process. To-day, not yet thirty-five years from the time when the announcement was made, it may be said to have revolutionised the iron and steel trade of the world. The whole product of steel of all kinds made prior to his invention was insignificant. To-day, the production has reached 10,500,000 tons, being more than one-third of the whole consumption of iron in the world. It is still rapidly advancing upon the domain occupied by the ordinary iron of commerce, and it is quite evident that the time is not far distant when the use of that commodity will be restricted to special purposes, serving to remind us of processes which otherwise would have been consigned to history.

I do not propose to enlarge upon the practical application of the Bessemer process to the manufacture of steel; but, if you will bear with me, I think it would be well to direct attention to the effects of this invention upon the economic, social, and political condition of the world. A very few considerations will serve to show that the Bessemer invention takes its rank with the great events which have changed the face of society since the time of the Middle Ages. The invention of printing, the construction of the magnetic compass, the discovery of America, and the introduction of the steam-engine, are the only capital events in modern history which belong to the same category as the Bessemer process. They are all examples of the law of progress which evolves moral and social results from material development. The face of society has been transformed by these discoveries and inventions. It is inconceivable to us how the world even existed without these appliances of modern civilisation, and it is quite certain that if we were deprived of the results of these inventions, the greater portion of the human race would perish by starvation, and the remainder would relapse into barbarism. I know it is very high praise to class the invention of Bessemer with these great achievements, but I think a candid survey of the situation will lead us to the conclusion that no one of them has been more potent in preparing the way for the higher civilisation which awaits the coming century than the pneumatic process for the manufacture of steel. Its influence can now be traced, although future results are still beyond the reach of the imagination.

Its principal characteristic is to be found in its cheapness. Steel is now produced at a cost less than that of common iron. This has led to an enormous extension in its use, and to a great reduction in the cost of the machinery which carries on the operations of society. The effect has been most marked in three particulars: First, The cost of constructing railways has been so greatly lessened as to permit of their extension into sparsely inhabited regions, and the consequent occupation of distant territory otherwise beyond the reach of settlement. Second, The cost of transportation has been reduced to so low a point as to bring into the markets of the world crude products which formerly would not bear removal, and were thus excluded from the exchanges of commerce. The practical result of these two causes has been to reduce the value of food products throughout the civilised world; and inasmuch as cheap food is the basis of all industrial development and the necessary condition for the amelioration of humanity, the present generation has witnessed a general rise in the wages of labour, accompanied by a fall in the price of the food which it consumes. I think it would be a very modest estimate of the improvement in the condition of the working classes as a whole to say that in the essential elements of comfort the working classes of our day are enabled to earn and to expend at least double the amount which was at their command in any previous age of the world. This result appears to me to be due very largely, if not altogether, to the economy in the agencies of production made by the cheap steel of the Bessemer process, and of the other inventions which have followed in its wake. These are material results, but they are accompanied with the slow but sure elevation of the great mass of society to a higher plane of intelligence and aspiration. No better evidence of this can be afforded than the association of working-men together for the advancement of their mutual and social condition. Troublesome as the trades unions may have been, they indicate a step in advance which should be the subject of congratulation among all well-wishers of the race. I see nothing but good to come out of the modern tendency to association, and I hold it to be one of the chief glories of Sir Henry Bessemer that he has contributed more than any other living man to that condition of industry which compels all who are engaged in its conduct to combine on a scale unknown before his time in the work of economic production and equitable distribution.

The first striking result in the cheapening of the cost of the production and transportation of food products was felt in Great Britain, which is now compelled to import at least two-thirds of its consumption. The competition of our western wheat regions with the products of India in the English market altered the whole condition of agriculture in the British Isles. The profitable raising of wheat practically became impossible, and the farmers who had depended upon it could no longer pay the rents stipulated in their leases. A general reduction of rent, therefore, became necessary, which of course reduced the income of the landlords. The aristocracy of Great Britain is a survival of previous conditions, depending for its existence upon the ownership of the land, and the revenue derived from it. Hence a serious if not fatal blow at the domination of what may be termed the privileged class of Great Britain was struck, unintentionally, doubtless, by the invention of Bessemer. We have not yet seen the final result of the competition it has introduced, but enough is apparent to show that the structure of the British Government will necessarily undergo very serious changes, all tending to the transfer of power from those who own the land to the commercial, manufacturing, and working classes of the people. I think it is doubtful whether any event in modern times of equal significance has occurred. Sir Henry Bessemer has certainly been the great apostle of democracy; and although he may be inclined to disavow the claim, history will record the fact that he has been the most potent factor in the reconstruction of the British Constitution upon the basis, ultimately to be reached, of universal suffrage.

Turning from Great Britain to this country, the effects of the Bessemer invention have been even more pronounced and striking. The cheapening in the cost of transportation enabled us to increase enormously the sales of food products in foreign markets. In accordance with the well-known law of commerce that a nation cannot sell without buying, our imports of foreign merchandise have been increased in a corresponding degree. Under our fiscal system, made necessary by the war for the Union, a revenue has been derived enabling us to reduce our national debt in twenty-five years from about four thousand millions of dollars to less than nine hundred millions of dollars at the present time, notwithstanding the payment of a pension roll which now amounts to fully one hundred and twenty millions of dollars per annum. We can trace, therefore, directly to the Bessemer invention the ability to reduce our national debt, and finally to pay off the outstanding bonds at maturity. This proposition can easily be verified by examining the results of the operation of our railroads, by which it will appear that since 1870, when Bessemer rails began to be largely used, the rate of transportation has been reduced about two-thirds, and an eminent authority has recently stated that the difference in a single year would now amount to one thousand millions of dollars, a very large portion of which is directly traceable to the greater durability of the track, due to steel rails and the capacity to haul increased loads, not only in the cars, but in the train. I doubt whether it ever occurred to Sir Henry Bessemer to consider the effect of his invention in furnishing us the means of paying off our national debt, but it certainly ought to secure for him the gratitude of every American citizen; and I am glad to have the opportunity, on this occasion, to bring this obligation to the notice of my countrymen.

The third point to which I would call attention is the vast extension and new direction of commerce which has resulted from the construction of steel vessels. The size of these vessels has enormously increased, and the cost of operating them has been reduced in a corresponding degree, comparing very favourably with the reduction of cost upon land, which is about one-third of what it was ten years ago. The characteristic of modern commerce is in the rapidity with which exchanges are made, and in the fact that all portions of the habitable globe are quickly reached. The commercial world has been converted into a vast clearing-house for the exchange of products. One country may sell more than it buys, or buy more than it sells, to a particular country, but the difference is counterbalanced by a corresponding sale and purchase from some other country. The balances are not paid in money, but are passed to the credit of each country in the general settlement which takes place in the banking centres of the commercial world. Thus the function of the precious metals is reduced simply to the payment of final balances, which, in the course of any one year, are small in amount. The economy in exchange thus effected is largely due to the improvement in transportation, made possible by the general use of steel, aided by the telegraph, and particularly by the submarine cables which now reach every part of the civilised world. The interdependence of the human race has thus been increased, and the possibilities of hostile action by war diminished, in a corresponding degree. The name of Bessemer will, therefore, be added to the honourable roll of men who have succeeded in spreading the gospel of "Peace on earth and good-will towards men," which our Divine Master came on earth to teach and to encourage.

I have some hesitation, in conclusion, in referring to another point which seems to me to be required in order to complete this hasty reference to the claims of Sir Henry Bessemer to the admiration and gratitude of mankind. It is to be hoped that out of the stupendous results of his genius he has acquired for himself an ample fortune. How large the amount may be I have no means of knowing, but if he should be in the receipt of even a small percentage of the annual saving to society, he would have the largest income of all men in the world. It is the fashion of the day to rail at the possessors of large fortunes, and there are people who imagine that they have been wronged by the existence of such aggregations of wealth. It is doubtful whether, in proportion to the total wealth of mankind, the portion which may be controlled by the few who are recognised as great capitalists is as large in our time as in other ages of the world. But even if the case were otherwise, no man can allege that he is not a positive gainer by the results of the Bessemer invention, or that he suffers loss or damage in any way from the fact that Bessemer has secured for himself a small portion of the benefits which his genius has conferred upon mankind. His example is of inestimable value, therefore, in showing that the existence of large fortunes, as a rule, is the evidence of benefactions vastly greater to the wealth of the world, by which all have gained and none have lost. Although there are undoubtedly striking exceptions to this general rule in the possession of fortunes, due to accident, or even to fraud, these exceptions only serve to call public attention to the real question which underlies the accumulation of wealth in private hands, namely, the mode in which it is used by the possessors. A great capital is a great blessing if it is employed in adding to the resources and advancing the civilisation of the world. It is a curse only when it is used for demoralising expenditure and vicious indulgence. The career of Bessemer, therefore, is admirable, not only in having added to the general wealth, but in the employment of his share of the proceeds of his invention for the spread of knowledge, the progress of industry, and the reward of efforts to promote the welfare of the race. He is now in the evening of his days, but he is also at the summit of his fame, for he has lived to see the marvellous fruits of his genius in the advancement of his fellow-men to a higher plane of comfort and intelligence than has been possible in any previous age.

I think, therefore, Mr. President, that I am justified in asking you to carry back to Sir Henry Bessemer the grateful regards of his kin beyond the sea, whose homes he has multiplied, whose country he has developed, whose burdens of debt he has lightened, and whose progress in all the arts of civilisation he has placed upon a basis as durable as the material with which his name will ever be associated.

The following paper was then read:—

NOTES ON THE BESSEMER PROCESS

By HENRY M. HOWE, A.M., S.B., Boston, U.S.A.

The striking features of American Bessemer practice are its large output and its low initial silicon and initial temperature. These are interdependent. Large output implies short blows and short intervals between blows. Short blows imply low silicon and fast blowing. Low silicon implies short intervals and fast blowing. Our blows are short because we have little silicon to remove, and because we remove it fast by supplying blast rapidly. We get enough heat even with little silicon, because our blows and the intervals between them are so short that relatively little heat escapes from our vessels. Were we to lengthen our intervals, or to blow more slowly, we would have to meet the increased loss of heat from our vessels, either by using more silicon, or by melting hotter, *i.e.*, by burning more coke, in the blast furnace or in the cupola. Finally, our short intervals imply powerful machinery, efficient organisation, and extreme specialisation and subdivision of labour, which can be profitable only when the output is large.

Let us now take these points up in more detail, first glancing at some examples of our large outputs, given in Table I., and of the composition of our iron.

TABLE I.—*Output of American Bessemer Works and Rail-Trains.*

	Date.	Name of Works.	Ingots from One Pit.								Number of Shifts in the Month.	Rails.						
			Tons.				Heats.					Tons.				Rails.		
			Per 12 Hours.	Per 24 Hours.	Per Week.	Per Month.	Per 12 Hours.	Per 24 Hours.	Per Week.	Per Month.		Per 12 Hours.	Per 24 Hours.	Per Week.	Per Month.	Per 12 Hours.	Per Week.	Per Month.
2-Vessel Plants.	1889.	Homestead rail steel	477	891	4,477	19,572	91·5	170	809	3,636	71	...	...	...	...	...	...	...
	...	Homestead soft steel	372	619	...	13,291	69	116	...	2,436	71	...	...	...	...	...	...	...
	March 1889.	Scranton	...	...	...	18,303	...	...	...	...	47	...	...	...	...	...	...	15,879
	July 1889.	Union	...	1,408	7,024	...	...	...	...	...	...	...	1,149	5,783	...	...	19,392*	...
	Oct. 1889.	Scranton	488	...	...	...	76	...	...	...	...	454·5	...	...	...	1,818	...	...
	Oct. 1889.	Union (10 tons)	852	1,639	8,549	36,232	85†	164†	855†	3,623†	54	660	1,312	6,766	28,491	...	...	...
	Nov. 1889.	Scranton (6½ tons)	491·8	975	...	...	71	141	...	...	...	...	...	...	...	...	...	...
	Dec. 1889.	Scranton	501	...	...	...	73	...	...	...	...	...	...	...	...	...	...	...
	March 1890.	Scranton	...	...	5,456.7	...	...	...	...	...	...	...	...	...	...	...	...	...
	...	Harrisburg	544	1,029	5,110	20,947	75	141	678	2,929	48	...	...	...	...	...	...	...
	...	South Chicago	701	1,393	6,402	27,427	60	119	556	2,441	50	...	...	...	...	...	...	...
3-Vessel Plants.	Oct. 1889.	Edgar Thomson	...	...	7,225	...	...	...	664	...	...	...	...	...	...	...	12,073	...
	Jan. 1890.	Edgar Thomson	...	...	...	...	...	...	...	...	...	...	1,250	...	...	2,502·9	...	...
	Feb. 1890.	Edgar Thomson	...	...	...	...	...	...	...	...	...	...	...	...	25,600	...	...	...
	March 1890.	Edgar Thomson	...	1,648	...	...	...	...	...	...	...	...	1,417	...	...	...	...	...

* Calculated. During ten out of the eleven shifts 66-lb. rails were rolled, and on the eleventh shift 75-lb. rails. Assuming that the average weight of the rails was $\frac{66 \times 10 + 75}{11} = 66{\cdot}8$ lbs., the number of rails would be 19,392.

† Calculated, assuming that the average weight of ingots per heat was 10 tons, which is the nominal weight.

Output.—On presenting such results to some foreign metallurgists, I have been told, "Oh yes, we quite understand that. You really turn out no more steel than we do. As a matter of personal pride, your manager gets up a tremendous spurt for a day, or even a week, crowds on men wastefully, rushes through great quantities of metal, and then for months afterwards has to recuperate. The machinery has been strained; the owners' money has been wasted; the men have been prostrated—all to gratify the manager's vanity. Your average output is no larger than ours."

Personal pride has, doubtless, played its part; without it we would still be savages, or apes, or mollusks, if you prefer. These baser motives are the mudsills of progress, the soiled roots of that growth of which civilisation is the flower. Great outputs were made and published: generous rivalry sprang up. Each showed the other how he made his great output, each gained the experience bought by the other's toil, till the average output of to-day is far greater than the boasted record-breaking output of our centennial year. Whatever may be the merits of our tariff system, we have pushed free-trade far in some important directions—free-trade in ideas, free-trade in land, free-trade in labour.

Is the charge true that our great outputs are but isolated *tours de force*, rising like Teneriffe above the dead level of our everyday mediocrity? I have before me the returns from the Adonde * (American) Bessemer works, from July 1, 1889, to June 1–30, 1890, a period of fifty-two weeks and one working day. As we work eleven shifts a week, this gives a total of 574 shifts available for work. But the period actually comprised in the returns covers four additional shifts, or a total of 578 shifts. Out of these the Bessemer mill ran during 542 shifts, leaving thirty-six idle shifts to cover holidays, strikes, and stoppages for repairs and lack of orders. Three of these were for celebrating the national holiday; thirteen at the winter holiday season for general repairs; nine owing to a strike; and eleven owing to an order from the directors, for reasons of which I am ignorant. The works have two 10-ton vessels. The total annual output was 318,635 tons, which implies an average output of 26,553 tons per month, or of

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* I use cipher names expressly to avoid indicating what works are referred to. For the like reason, I decline to state whether I always refer to the same works in the same way or not.

1176 tons, or about 118 blows per twenty-four hours, or of one blow every 12·2 minutes the whole year through. During the same period 260,881 tons of rails were made, which implies an average output of 489·5 tons per shift, or 979 tons per twenty-four hours, or 5384 per week. Less than ten years ago Captain Jones described to you his work during the preceding year, in which he had made 128,303 tons of ingots. He gave it as his belief that we were then on the verge of the elastic limit of production, though he thought that in a long month 15,000 tons might be made. Thus in about nine years our output has increased more than two-and-a-half-fold. Captain Jones' supposed elastic limit has proved to be no breaking-down point; under a stress more than twice as great no contraction of area occurs, and our ultimate strength is not yet in sight.*

It is reported that the Scranton works, with two 6·5-ton vessels, made 104,441 tons of rails during the first six months of this year. This implies an average of about 144 heats per twenty-four hours, or a heat every ten minutes during the whole of this period, and of at least 4017 tons of rails per week.

Proportion of Silicon in the Vessel-Charge.†—While there are American mills, and good ones, which habitually have 2 and even 2·25 per cent. of silicon in the vessel-charge, and while I know cases in which the silicon-content has reached 6·9 per cent., the majority of mills have less than 1·75 per cent.; and what appears to me the most characteristically American practice has habitually but from 0·6 to 0·9 per cent. of silicon in the vessel-charge. ‡ I have before me returns from a number of successive heats, whose composition lay between the following limits; they represent the favourite practice at Ningunaparte, except that the manganese is a little higher than usual.

Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
3·36-3·66	·64-·80	·49-·70	·079-·086	·053-·075

In another case the silicon in ten consecutive heats lay between

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* *Journal of the Iron and Steel Institute*, 1881, I., p. 129.

† I invariably refer to the average percentage of silicon of the whole vessel-charge, scrap included, taken as it goes to the vessel itself. From the numbers which I give, the loss of silicon in the cupola has already been deducted.

‡ The words "characteristically American" must be taken in their exact sense. I do not mean that this is the habitual American practice. It is not. But it is most characteristically American to carry on operations so extremely rapidly, and hence with so small a proportion of loss of heat, as to permit this low silicon content, and, unhampered by precedent, to use it boldly.

0·54 and 0·78 per cent., averaging 0·668. The iron was melted in cupolas with one part of coke to 11·77 of metal.

	Per Cent.
The loss for the month (including cupola-loss) was	7·89*
The proportion of scrap was	5·09
The yield of ingots per 100 of cast iron was	87·02
	100·00

At this mill less than 16 lbs. of coal per 2240 lbs. of ingots is used in heating the vessels and ladles, according to the yearly returns.

In order to blow iron with so little silicon successfully, the heats must follow each other quickly, and vessels and ladles must be hot. In running at the rate of five heats an hour, the metal whose composition I have given, with 0·64 to 0·80 per cent. of silicon, might be further diluted with 5 per cent. of scrap, reducing its silicon-content to between 0·61 and 0·76 per cent. If, on the other hand, only 1·5 heats were blown per hour in each vessel, the iron should have about 1·25 per cent. of silicon. Indeed, I think that most of those who use less silicon than this still admit that, as far as mere convenience of blowing is concerned, 1·25 per cent. is the best proportion.

Iron with much less silicon has actually been blown. It is stated that white iron containing 0·12 per cent. of silicon, and but little manganese, was once blown: and I know that iron with 0·25 per cent. of silicon and 1 per cent. of manganese has been blown intentionally, sandwiched between normally hot heats.

Metal with only 0·50 per cent. of silicon has been blown in Sweden;† but I understand that this was done only when the initial temperature was decidedly high. The practice which I have described, however, is that which Dr. Müller, in his admirable study of the German Bessemer process, called "the fourth and practically impossible variety of the Bessemer process, low initial temperature and low silicon-content." ‡

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* It is certain that this is the monthly loss recorded in the books of the establishment; but as it represents the returns for a single month only, errors in weighing and in estimating stocks may have distorted it somewhat. It is given here simply to show that, at least, no excessive loss occurred, and that the remarkably low proportion of silicon in the pig iron cannot be explained away by supposing that an excessive quantity of iron was oxidised in its stead to generate heat, either in cupola or converter. The loss at this same mill for the third quarter of 1890 was 8·8, the scrap 3·2, and the yield of ingots 88 per 100 of pig iron. Very careful attention is now paid to weighing, and the management is confident that these numbers are accurate.

† Chernoff, *Metallurgical Review*, vol. i. p. 352.

‡ "Die vierte Variation, niedrige Anfangstemperatur und niedriger Siliciumgehalt, ist praktisch unmöglich."—*Zeit. Vereins. Deut. Ingenieure*, 1878.

Low-silicon pig has, besides the advantages already referred to of being a relatively cheap pig to make, and of permitting large output, the further advantages of implying small loss of weight in conversion, little wear and tear of refractory materials, and little power for blowing.

It costs much to put silicon into pig iron, and much to take it out again. Not only does its own removal in the Bessemer process mean a loss of weight, but it drags much iron off with it into the slag. Further, by lengthening the blow it increases the wear and tear of the tuyeres, and of the refractory lining of the vessel and bottom; and every pound of silica thus abraded or corroded implies further scorification and a loss of about a pound of iron, besides implying expense for buying, preparing, and setting in place new refractory material in its stead. Finally, the blast needed for its removal implies expense for fuel, for wages of engineers and firemen, and for wear and tear of engines and boilers.

For all these reasons, the less silicon we can get on with the better; and much the same may be said of manganese. Coke is cheaper than silicon. It pays to burn an excess of coke in the cupola, if by thus increasing the metal's actual heat we lessen proportionally the potential heat—that is, the silicon—which it must have. But in our practice this is unnecessary, thanks to our quick blowing and short intervals: we use only enough coke to thoroughly liquefy the iron.

Rate of Removal of Non-Ferrous Elements.—Fig. 1 and Table II., which give the composition of the metal and the slag at different periods in a typical American blow, are based on the results of a laborious investigation carried out for this paper by Mr. Frank Julian, chief chemist of the Illinois Steel Company's works at South Chicago. Our hearty thanks are due him.

There appears to be a slight removal of phosphorus. As the loss of weight in conversion was 9·37 per cent., the resulting steel should contain 0·116 per cent. of phosphorus, if all the phosphorus present in the initial charge were concentrated in it. Actually the steel contains 0·109 per cent., the discrepancy being 0·007 per cent., or 1·59 pounds of phosphorus; certainly a very small quantity when distributed over ten tons of metal. The slag contains a small quantity of phosphorus, which increases up to the time of adding the spiegeleisen, when it again falls off.

Unfortunately the weight of the final slag is unknown; but, from internal evidence, I estimate that it was probably between 1200 and 1900 pounds; and hence that, containing as it did 0·010 per cent. of phosphorus, it should have held between 0·12 and 0·19 pounds of this element.

Can so silicious a slag contain even this trifling proportion of phosphorus, in presence of molten iron? It is possible that the phosphorus was not uniformly distributed throughout the slag, but was scorified locally from shots of iron during and after the removal of the slag from the vessel. These shots, suspended in the slag, would oxidise, surrounding themselves with a little shell of slag more highly ferruginous than the great mass in which they were suspended, and from them phosphorus would pass into this locally basic layer of slag. It is true that metallic iron and magnetic oxides and silicates were removed by means of a magnet before analysing the slag. But while the layers of slag immediately against the shots of metal might well be sufficiently magnetic to be thus removed, some of the phosphorus might well pass beyond these magnetic layers into outer ones, which, though still basic enough to retain phosphorus, were not ferruginous enough to be readily separated magnetically. The fact that the weight of phosphorus accounted for by the slag is only about one-tenth of that apparently lost by the metal, agrees with this view; most of that scorified remaining in the magnetic inner layers of slag next the shots, and being separated thus by the magnet.

A very appreciable quantity of phosphorus may, however, exist in a silicious slag under favourable conditions. Thus, a heat was very badly overblown at the North Chicago Steel Works in 1878, so badly that only two ingots were made; but the full charge of spiegeleisen, intended for normal conditions, was added on recarburising. The composition of the resulting metal and slag was as follows:—

The Metal.	Per Cent.
Carbon	·70
Silicon	·085
Phosphorus . . .	·157
Manganese . . .	·93

The Slag.	Per Cent.
Manganous oxide . .	2·68
Ferrous oxide . .	46·20
Silica	41·30
Alumina	5·50
Phosphorus . . .	·03
	95·71

As the spiegeleisen doubtless dragged much of the phosphorus back from slag to metal, there is every reason to believe that this decidedly acid slag, before recarburising, held much more than 0·08 per cent. of phosphorus.*

The gradual increase of phosphorus in the slag till the end of the blow, and its sudden fall on recarburising, may possibly be connected with the growing viscidity of the slag, as its proportion of silica increases from 42·40 to 63·56 per cent. towards the end of the blow, and with its again becoming more liquid, as its content of manganous oxide rose from 8·88 to 13·72 per cent. on recarburising, the quantity of shots suspended increasing with the viscidity of the slag. But I think that a more important factor is the progressive diminution in the proportion of carbon and silicon contained in the metal, which thus held its phosphorus less and less tenaciously, and acted less and less energetically in deoxidising phosphates in the surrounding slag. So, too, the gain in carbon and manganese on recarburising, with consequent increased resistance to scorification of phosphorus, goes to explain the sudden fall in the phosphorus content of the slag at the end.

TABLE II.—*Removal of Non-Ferrous Elements.*—F. JULIAN.

Description.	Initial Charge.			Time of Actual Blowing.						
	Molten Metal.	Steel Scrap, Estimated.	Average.	2 Min. 0 Sec.	3 Min. 20 Sec.	6 Min. 3 Sec.	8 Min. 8 Sec.	9 Min. 10 Sec.	9 Min. 20 Sec. A.	After adding Spiegeleisen.
Carbon . . .	3·10	0·36	2·98	2·94	2·71	1·72	0·53	0·04	4·64	0·45
Silicon . . .	0·98	0·08	0·94	0·63	0·33	0·03	0·03	0·02	0·35	0·038
Manganese . .	0·40	0·97	1·43	0·09	0·04	0·03	0·01	0·01	14·90	1·15
Phosphorus .	0·101	0·10	...	0·104	0·106	0·106	0·017	0·018	0·139	0·109
Sulphur . . .	0·06	0·08	0·06	0·06	0·06	0·06	0·06	0·06	...	0·059
Silica . . .	...	...	...	42·40	50·26	62·54	63·56	...	...	62·20
Alumina . .	...	...	...	5·63	5·13	4·06	3·01	...	...	2·76
Ferrous oxide .	...	...	...	40·29	34·24	21·26	21·39	...	...	17·44
Ferric oxide .	...	...	...	4·31	0·96	1·93	2·63	...	...	2·90
Mangan. oxide	...	...	...	6·54	7·90	8·79	8·88	...	...	13·72
Lime	...	...	...	1·22	0·91	0·88	0·90	...	...	·87
Magnesia . .	...	...	...	0·36	0·34	0·34	0·36	...	...	·29
Phosphorus .	...	...	...	0·008	0·008	0·010	0·014	...	...	·010
Sulphur . .	...	...	...	0·009	0·009	0·014	0·008	...	...	·011
Appearance of flame . . .	...	...	...	silicon flame	brightening	moderate carbon flame	full carbon flame	flame drops	blown 10 seconds after drop.	...
Cubic feet of air	...	...	...	34,502	30,628	53,481	45,365	26,430	1,868	...
Cubic feet of air per minute .	...	...	...	17,251	22,971	19,691	21,810	25,685	11,208	...

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* R. Forsyth, private communication, October 18, 1890.

Date, 1890.	Turn.	No. of Heat.	Converter Record.							Record of Blow.			
			Molten Metal.	Steel Scrap before Blow.	Steam Equal to Scrap.	Spiegel.	No. of Heat on Bottom.	Tuyeres.		Temperature.	Rate of Flowing.	Turned Down.	Spiegel Reaction.
								No. ⅜"	No. ½"				
Aug. 13	Day	18398	21500	1000	800	2500	4th	11	3	Medium	Quick	Fast	Medium

Date, 1890.	Turn.	No. of Heat.	Ladle Record.				Ingot Record.							Bloom Record.	Rail Record.		
			Rate of Flowing.	Nozzle.		Behaviour in Ladle.	Behaviour in Mouldings.	Temperature of Moulds.	Number of Ingots Cast.	Kind of Ingots.	Bend Test.	Time in Gir.			Weight per Yard.	No. Rolled.	Seconds %.
				Size.	Heat on Nozzle.							Hours.	Minutes.				
Aug. 13	Day.	1839	Fast	1⅜"	3rd	Quiet	Quiet	Warm	7⅔	80¼	Left R.A.	1	23	Clean, without cracks	80⅝	23	0

NOTE.—*A*. Sample V. was taken after blowing 9 minutes and 10 seconds. The vessel was then turned up again, and blowing was continued for 10 seconds more, when the spiegeleisen was added, no sample of either metal or slag being taken before adding it. After adding it, Sample VI. of both slag and metal was taken.

B. The volume of blast is calculated from the volume of the blast cylinders, without deducting for leakage or clearance.

The barometer in the engine-room read 29·79 inches; the temperature was 36° C. (96·8° F.) in the engine-room. The blast pressure was 27 lbs. per square inch.

Each of the fourteen tuyeres has twelve holes. Those in eleven of the tuyeres are ⅜ inch in diameter: those in the remaining three tuyeres are ½ inch in diameter.

Length of Blow.—This depends on the composition of the iron, the blast-pressure, the area of the tuyere-holes per ton of metal in the charge, and the depth of the bath of metal in the converter. Our blast-pressure usually lies between 20 and 25 lbs. per square inch, and we provide from 2 to 4 square inches of tuyere-hole area per ton of metal. These conditions are thus about the same as in modern European practice. The chief reason why our blows are so much shorter than the European ones, then, is that our iron is so relatively free from silicon; but our bath of metal may be enough shallower than the European to contribute to the result. The length of the blow in our fast-running works is usually from eight to fourteen minutes, though it is rather longer than this when direct-metal is used. The

Union, Scranton, and Homestead works have each run for a whole shift at the rate of one heat in 9·86, in 9·23, and in 7·87

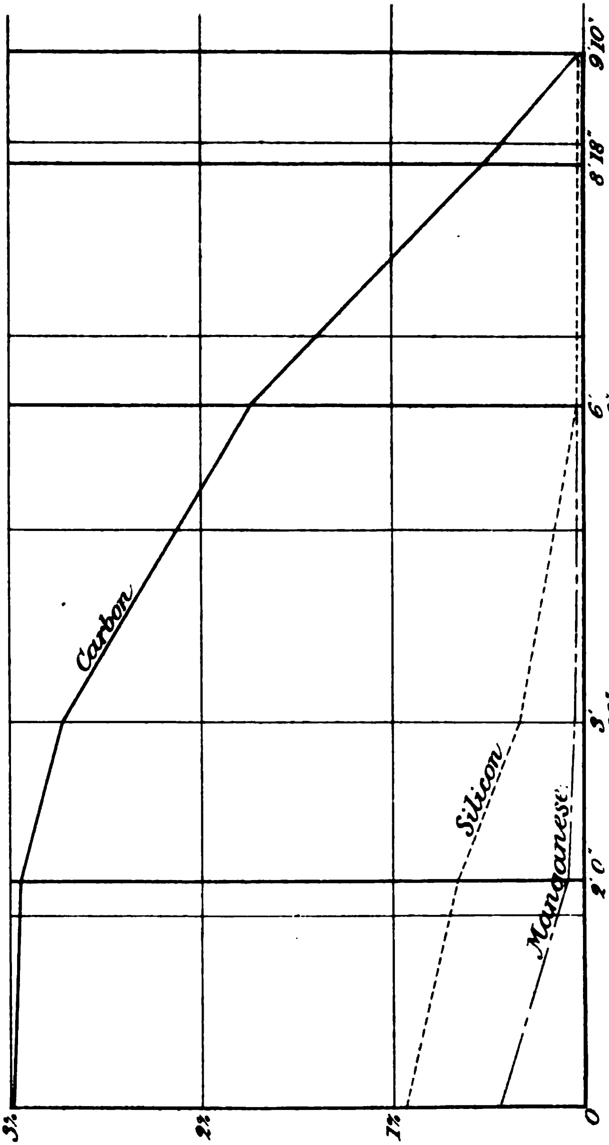

Fig. 1.—Removal of Non-Ferrous Elements.

minutes respectively. The depth of metal in our newer vessels is usually from 12·5 to 15·5 inches.

Heavy blast-pressure of course costs more than light for steam, and for wear and tear of boilers and engines. It has the compensating advantage of prolonging the life of the bottoms. On the one hand it protects the bottom by lifting the metal, there charged with most corrosive iron-oxide, away from the tuyere-ends; and by cooling those tuyere-ends, both by holding the hot metal away from them, and by causing vaster volumes of rapidly expanding, and hence cooling, air to pass through them. On the other hand, the increased velocity of the air tends to increase the abrasion or corrosion of the tuyere-ends. As might be expected, experience indicates that its protective greatly outweighs its injurious effect; and that increasing the blast-pressure lengthens the life of the bottoms. Up to what pressure it would, on this account, pay to compress the blast must depend on the relative cost of steam and of bottoms. I can only say that our best engineers think that we have not passed the limit of economy. The fact that, though we use non-compound and not particularly economical blowing-engines, the total fuel-consumption for steam is sometimes only about 200 lbs.* per ton of ingots, or 9 per cent., harmonises with this belief. Usually, however, the boiler-coal consumption per ton of ingots is larger than this: the yearly returns for one very well managed works making an enormous output, and using, I believe, the poor Illinois coal, give it as 309 lbs.; those of another, also making an enormous output, but not so well managed, give it as 350 lbs. In still another old but well-managed mill it rises to about 400 lbs.

Large Outputs.—Turning next to our large outputs, one naturally asks, "How are they made?" and "Do they pay?"

One of the two essentials of large output, short heats, we have already considered. The other, short intervals between heats, implies such arrangements for preparing the cast iron, for conversion, for teeming the steel, and for stripping and removing ingots and setting moulds, that no one of these operations shall be greatly delayed in waiting for another; and enough pit-room to accommodate the ingots resulting from several blows, so that each ingot may stand in its mould long enough to cool and solidify, without delaying the teeming of subsequent heats. If we seek very large output, then, as soon as a heat is blown in one vessel, and before it is recarburised, a second must begin blowing in another vessel; and the first vessel, or the third, if there be three, must be ready, so that a third heat may begin blowing as soon as the second is blown. The casting-ladle must receive and deliver its steel, undergo its repairs, and be back ready to receive the second heat as soon as the second heat is ready to be poured into it. So, too, a second set of moulds must be ready to receive the second heat as soon as the casting-ladle has received this second heat and swung around to where the moulds stand, and so on.

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* The manager of one of our largest steel works writes me (August 7, 1890) that a careful estimate, covering a continuous run of eighteen months, gave the coal, which was anthracite of a common grade, used for steam-raising in the (Bessemer) converting department, as between 205 and 206 lbs. per 2240 lbs. of ingots.

Five large cupolas, with abundant blast, or ample arrangements for bringing metal direct from the blast furnace, according to whether cupola- or direct-metal be used; a swift moving casting-crane, at least 60 feet along the rim of the casting-pit available for ingot-moulds, or room for at least four sets of ingot-moulds; four ingot-cranes; blowing-engines, pumps, and hydraulic apparatus, capable of running continuously for a week without a moment's stoppage; hydraulic pressure-pipes that can neither burst nor freeze; ample boiler capacity;—these are what the mechanical engineer must supply. The administrative head must arrange that sufficient stores of pig iron, ferro-manganese and spiegel; of coal and coke; of refractory materials, and of moulds, shall be ever at hand, and reach promptly the cupolas, boilers, repair-shops, and mould-yard. He must organise the many groups of workmen needed, each group self-contained and looking to one definite director within or without its own limits, yet each co-operating with the rest; for stocking the cupolas, for charging, tapping, and repairing them; one group charged with the care and repairs of the vessels; another with making the vessel-bottoms; another with the recarburiser; another controlling the length and temperature of the blow: but stay—Appendix A gives a list of the thirty-four distinct groups of men employed on each shift at the Mugby Junction (American) Steel Works, besides the six groups employed for current repairs on Sundays.

But note that there is absolutely no mystery about it. Almost no chemical knowledge is needed. A good mechanical engineer to build, a good administrator to manage—to select his men with judgment, to treat them with gentle, just firmness. One who can by appeal, now to pride, now to cupidity, identify the interests of men and of masters; who, with contagious zeal, can exact earnest, intelligent, and prolonged efforts from all, while overtaxing and oppressing none; whose deft, velvet-gloved iron fingers can hold a thousand reins, keeping at each moment the needed but varying tension on each; who, ever watching each item of cost, pares each to the limit of safety. All this you knew before; here is no more mystery than in putting up a 100-lb. dumb-bell. Given the strength of mind or of muscle, and it is simple enough. What mystery in Patti's carolling, in Napoleon's conquests, in Shakespeare's master-works, in your cricketer's batting? Merely skill, or if you prefer, skill and strength, now of one kind, now of another.

But does it all pay? Excessive pace kills both horse and man. Remember the hare and the tortoise. He who works fourteen hours a day, seven days a week, and fifty-two weeks a year, so shortens his working life that he accomplishes less than the more moderate worker. *In medio tutissimus ibis.* You Americans go at such a pace that you wear out your lives and your machinery. Your large outputs cost you more per ton of ingots than our small ones.

Such similes, such rebukes are familiar to most American metallurgists who have visited European works. While there may be a certain residuum of truth in them, there is certainly an incomparably greater mass of fallacy.

Effect of Rapid Running on the Machinery.—Let us consider first the machinery; next, the men.

Realise first that greater output does not necessarily imply that any of the machinery moves faster; it may be, and in great part is, due to shorter intervals of rest and disuse. It means more nearly continuous, rather than swifter movements. The frequent and long repose that animals need, "that knits up the ravelled sleave of care," machinery needs not, and is not benefited by. It is not true that an engine which runs continuously from Monday morning to Saturday night will necessarily make fewer revolutions before wearing out than one which makes but one-half or one-third as many like revolutions at like speed each week. Indeed, some might go farther, and, pointing to the settling of foundations, the accumulation of grit on bearings, the rusting which occurs during rest as well as during work, and to the stresses set up by heating and cooling, expansion and contraction, each time the engine is started and again set at rest, might claim that, given occasional intervals for alignment and current repairs, the continuously-running engine should make more revolutions before wearing out than the one used intermittently.

Again, faster blowing implies delivering more blast per second; but it does not imply that the engines must run faster, for it may be attained by making them larger.

Holding thus that our system of enormous output from works intelligently designed for it implies no necessary waste or injury to machinery, I must admit that it tends strongly to induce more rapid movements of the machinery, which surely tend to shorten its life. But is not the tendency of modern engineering towards greater speed? Is it not thought that the saving interest in labour and steam outweighs the cost of the increased wear due to greater speed?

But I anticipate the argument. Finding deductively no strong reason to expect that our larger outputs imply wasteful use of machinery, let us turn to induction, and see what the wear and tear of our machinery actually is.

The first American Bessemer works were built at Troy and Wyandotte in 1864. The Wyandotte works were abandoned in 1869; but one of their old cranes is still in vigorous activity at the Bessemer works at North Chicago, which for a time excelled all others in size of output. This archaic crane has indeed received a new plunger, but has undergone no other renewals, and, after more than a quarter of a century of our American high-pressure system, does two-thirds of the work of its mill.

The Troy works, burnt down in 1868, were rebuilt in 1869, still in an experimental way. The subsequent doubling of the weight of the charges has necessitated changing most of the machinery; but the old blowing-engines are still in constant use.

The same cause, increasing the weight of the charges, has led to renewal of much of the machinery in most of the older works.

But at the North Chicago Bessemer Works, started in 1872, the original cupolas (both for cast iron and for spiegeleisen), vessels, cranes, ladles, pumps and engines, are still in service without renewals, save the single crane-plunger already noted, and the centre section of each vessel. The bodies of the iron cupolas have been repaired, but the rest of the cupolas have needed nothing but an occasional coat of paint. All the original ladles are not only in use, but promise yet to do as much work as they have already done.

The Cambria Bessemer Works were built in 1868–9. The annual output has grown from 30,000 tons in 1873 to over 120,000 in 1880, and 210,000 in 1888. They long disputed with North Chicago the palm for great output. The greatly increased output and weight of charge have led to the abandonment of the original antiquated cupolas and of the ladle-crane; to enlarging the bottom-ovens, the stock hoist, and the end-sections of the converters; and to erecting additional boilers and engines. While the original ladles have been worn out, the original ingot-cranes, boilers,* pressure-pumps, and blowing-engines are still serviceable and in use. The original reverberatory spiegel-furnaces, pressure-pumps, and fan-blowers have given place to cupolas, compound pumping engines, and Baker blowers. But for the ladles, one might say that all the original permanent plant was still in use, except what had grown unbearably antiquated, and what could not be used because of the greater weight of charges—in short, except only what was outgrown.

So far as my inquiries have gone in the great majority of cases, machinery has been replaced, not because worn out, but, though still fit for the work for which it was designed, either because it was unequal to the enormously and unexpectedly increased duties due to increased weight of charge, or because it could be replaced advantageously by more efficient machinery of later, or at least better, design. In this day of rapid mechanical progress, it must often happen that machinery becomes antiquated long before it is worn out. The mammoth office buildings erected in my boyhood, with all the then modern improvements, are torn down to-day, not because worn out—they would stand for centuries—but solely because they are unsuited to to-day's needs. To the eye of progress we are still in the middle ages.

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* The original boilers have been re-tubed; the old pressure-pumps are now used as boiler feed-pumps; and the old ingot-cranes have been strengthened to meet the fourfold increase in the weight of the ingots, from about 1500 to 6500 lbs.

Now the length of time needed to render a machine antiquated, and to justify replacing it with a better, depends not on how much it works, and how much it rests, each day, but on the progress of the rest of the world.

Suppose that we have an engine which can make just one billion revolutions before wearing out. If mechanical progress be such that it compels us to displace this engine at the end of ten years, the proportion of the engine's first cost chargeable to each ton of product will be only one-tenth as great, in case it has then already made its billion revolutions, as if, thanks to leisurely interruptions, its average work has been at the rate of one billion revolutions in one hundred years. If a machine is to be thrown out before it can wear out, the charge for its cost against the unit of its useful work is inversely proportional to its average rate of work.

The same is true of the charges for interest, insurance, and taxes; while the fact that general charges, such as those for sale, advertisement, and collection, diminish with the volume of business, need not be dwelt on.

The Report of the United States Commissioner of Labour gives the cost of repairs and supplies at a single American rail-steel Bessemer works (and a slow-running one at that, making only 479 tons daily), as $0·453, against from $0·541 to $1·52, or an average of $1·07 for eight British and Continental rail-steel Bessemer works, three of them basic, five acid.* But such comparisons must be received very cautiously, owing to differences in book-keeping.

In the only case in which I have exact trustworthy data, the actual cost of repairs to an American Bessemer converting department, including cupolas, ingot locomotives, and cars, is $0·174 per ton of ingots.†

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* "A Preliminary Report on the Cost of Production of Pig-Iron, &c." By the Commissioner of Labour, Washington, 1890, p. 31–33.

† The cost of such repairs consists chiefly of the wages of machinists, blacksmiths, &c. In the neighbourhood of these works, labourers are paid $1·68 per twelve-hour shift; enginemen suitable for small locomotive, $2·50; enginemen for large engines, $3·25; blacksmiths, $2·50; handymen, attending to current repairs to machinery, $2·75.

To sum up, our system of large outputs then, on the one hand, certainly lowers the charges for installation, interest, taxes, and insurance ; on the other hand, the actual history of the machinery itself, and the actual cost of repairs in some of our oldest and most rapid works, by no means suggest that our high-pressure system causes excessive wear and tear, or that it lessens the grand total life's work of the machinery and plant. And this is easily understood on remembering that great output is due rather to shortened intervals of disuse than to rapid motion.

Effect of Rapid Running on Labour.—So much for the machinery. Turn we now to the men.

Larger outputs imply a larger number of men, without materially increasing the number of kinds of operations to be performed. Hence each man should become more skilled in the smaller range of operations to which his work is restricted. These he should perform, not only more quickly, hence accomplishing more useful work with a day's labour,* but with greater economy of power, of the fuel or other material which he uses, with less wear and tear of tools and machinery, and in general better, with results fitting more closely the general needs, and so lightening the labour of his co-workers, and lessening the needed supervision and instruction.

Or, if the sum of his useful work be not increased, its smaller range should permit us to employ less intelligent and costly men. In either case we have here a first gain.

Next, as operations succeeded each other more rapidly, so should a smaller proportion of the workmen's time be lost between them, if not in rest, at least in slackened activity.

Again, we cannot employ fractions of men. Where given work is two and a quarter times as much as one man can do, we must actually employ three. Here we have what I may call a *fractional excess* of three-fourths of a man. Now it should be clear that when, as in rapid running, many men are employed at a given task, this fractional excess tends to bear a smaller ratio to the whole, and hence to the output, than when few are employed.

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* Let us take as the unit of work a day's labour, that is to say, the labour of one man for one shift. It varies in value and cost, just as coal does; still, like the ton of coal, it is a better unit than the dollar's-worth, since it is free from one source of variation, the difference in the money-value of like kinds at different times nd places.

Finally, there is a certain nucleus of skilled men—blower, chemist, blacksmith, timekeeper, foreman, &c.—whose wages resemble the fixed charges of the railway more than do those of the other workmen, which rather resemble the working charges. I do not insist on an exact, but merely on an approximate resemblance. Now, clearly, the greater the output, the less heavily do these quasi-fixed charges fall on the unit of product.

It is not easy to see how rapid running should increase, to any considerable extent, the work to be done. At first sight one might suppose that there would be more work connected with the moulds, since in rapid running they must be specially cooled, while in leisurely work they cool soon enough spontaneously. But even with the enormous output at Adonde, two boys on each twelve-hour shift suffice for cooling the moulds. The labour connected with setting and stripping the moulds is no greater when they are artificially cooled between leaving and returning to the pit, than when they return to the pit immediately after leaving it. In either case the same number of operations is performed, and in the same way. The mould must be lifted from the ingot, set down, left while its ingot is taken from the pit, and then returned; in one case after cooling, or even after an excursion on its car to the mould-yard and back, in the other case immediately. In either case the ingot should be stripped as soon as possible, so as to save its initial heat; hence the trouble from temporary stickers should be the same in either case.

Next, when the intervals between heats are short, the vessel-linings and bottoms have little chance to cool; hence they should wear out more quickly, or at least the labour needed to keep them in order, by patching, blinding tuyeres, &c., should, it may be claimed, be greater than in case of more leisurely running. A partial answer to this is that the short intervals permit the use of low silicon, and hence short blows, and that the destructive effect of each blow must increase with its length.

A better answer, however, is that actually the number of days' labour of the vessel-men per ton of ingots, is less in swift-running American than in European Bessemer works, at least so far as my investigations go; indeed, in case of this group our labour-consumption compares exceptionally well with the European.

Again, it may be said that to move objects more rapidly calls for a greater expenditure of strength for each motion, and hence ultimately for a greater labour-consumption, by calling either for a shortened shift or for additional help. In the case of most of the operations connected with the converting department, however, greater output does not require that any one manual operation be performed more quickly, but merely that one succeeds another more quickly. Double the quantity of iron to be melted, and you must double the number of stockers and chargers, each of whom will still move at the same rate as before.

But where, as in the case of the cranes, the number of instruments available is limited, then, indeed, greatly increased output, while in part due to shorter intervals of rest, may well lead to more rapid movement. This objection to large outputs is met, however, by using mechanical appliances for rotating the cranes, as well as for lifting them. When this is done, and in many other cases, those of the engines, pumps, &c., in which the work is done by machinery, the workman simply directing, more rapid movement merely means that each workman directs more useful work per shift.

This question, then, whether increased output, in that it tends to induce more rapid movements, really calls for a considerably greater consumption of labour per unit of product, is one which each must answer for himself; but no valuable opinion can be formed without great familiarity with the work in hand, and careful observation. Personally, I am confident that it does not; but that, by compelling us to keep the machinery in the best order, and by leading to the adoption of better mechanical appliances, it eventually lessens the labour-consumption.

In considering this question, those inclined to the opposite view must bear a further distinction in mind. In order that the greater speed of working shall actually cost more, it must be so extremely excessive as to lessen the amount of useful work which each man accomplishes in a working day. Proof that the pace was such as to shorten his years of physical vigour, and thus lessen the amount which he can accomplish in his lifetime, would, I apprehend, count for little with directors and managers. The workman is paid, not for his lifetime, but for the number of days which he actually works, and at a rate which is governed chiefly by the law of supply and demand, by the attractiveness of his occupation, and perhaps by the endeavours of the trades-union—a point that we need not discuss—and but remotely and slightly, if at all, by the probable number of his working years. As humanitarians, we might regret such diminution of the gross sum of the workman's working power. As managers, hired by others to make money for them by metallurgy, we would be no more justified in diminishing our employer's profits by allotting to the workman less work than he willingly and knowingly, without deceit or pressure on our part, sought or accepted, than we would in substituting machine for hand-puddling, knowing the former to be less profitable, or in shortening the puddler's shift to four hours. The workman is a free agent.

But you will find no signs of unwholesome exhaustion in our Bessemer works. Go there unobserved: the cheery tones, the passing jest which you will hear, predict no early decay. No; in visiting our works, I recognise the faces which I knew there twenty years ago, still full of force.

Leaving now the quantity of labour, note that the average degree of intelligence needed, and hence the average cost of a day's labour, should be very much lessened by rapid running. One skilled chemist, one skilled mason, you must have, be your output large or small. One blower, one skilled engineman is needed, and suffices, whether you blow one or one hundred heats per shift, whether your engine runs continuously or but a tenth of the time. The difference is that, in case of small output, much of the time of these men, which you must pay for in full whether you use it or not, is either wasted or devoted to work which, in case of larger output, is performed by less intelligent, less skilled, less costly men. Shorten your blows, shorten your intervals, double your output, and you hardly need more of these highly-skilled men. Most of the additional men are less skilled; many, indeed, are but assistants of the skilled nucleus which is as necessary, and nearly as large, in the case of small as in that of large output. And though the chemist or engineman who is to direct others must add executive ability to the qualifications he would otherwise need, and hence commands higher pay, yet the extra expense thus caused should raise the average cost of the daily wages much less than it is lowered by the employment of the large number of relatively unskilled assistants, due to the greater output.

There are many trivial and very simple duties, which call for little intelligence. With large output, those of each kind recur so often that special, cheap men can be fully occupied with them. The expensive men, in cases of small output, do these trivial simple acts with their costly labour, which, in cases of large output, is restricted to the difficult tasks which require it, and which fully occupy it.

Or if, justified by the greater output, on the unit of which their pay forms a relatively small charge, you employ additional skilled and costly men, they are not mere duplicates of those you had before; they bring a different skill and additional knowledge to your aid, permitting economies, and devising improvements otherwise unattainable.

To sum this up, the greater skill due to the smaller range of duties; the shorter slack intervals between successive repetitions of the same work; the smaller ratio of fractional excess and of fixed charges, to all of which an increase of output should lead, should lessen the quantity of labour per ton of product. And while more rapid work might at first suggest more rapid, and hence more fatiguing, motions on the part of the men, and thus an increase in the labour-consumption, on closer view it is seen rather to mean more men, each moving at the same old rate, improved mechanism, and fuller substitution of machine for muscular power.

Further, increase of output, causing us to employ many relatively unskilled assistants to the costly skilled nucleus, should lower the average cost of a day's labour; or, giving us additional kinds of skill and knowledge, should lead to economies and improvements.

Turning now from deduction to induction, I must admit that, owing to the entanglement of causes, it would be difficult to prove by actual numbers that any saving in the consumption of tools and materials was due to the increased specialisation of labour, rather than to other co-existing causes; and, further, that I have not at hand data sufficient to prove directly that the greater output permits a lower average degree of intelligence, and thus a lower average price of a day's labour. But it is certainly very striking that, in the Mugby pay-roll in Appendix A, the rate of pay of 52·8 per cent. of the workmen indicates that they are wholly unskilled, mere labourers set at hard work. Their highest rate of pay is only 14 per cent. above that of the very cheapest men, the mere sweepers. This 52·8 per cent. includes less than half the stockers, none of the cupola-chargers, and none of the thirty-four pitmen proper.

Making a like study of the pay-roll of a continental establishment in 1881, I find that only 13 per cent. of the workmen can be classed as labourers, placing in this group all who do not receive more than 14 per cent. higher wages than the mere sweepers. This 13 per cent. includes one of the runner-men, an engine-tender, and all the blacksmith's helpers; indeed, quite as high a class of men as I include in this group at Mugby.

On the one hand, a single case, especially when at so remote a period, does not offer convincing evidence; on the other hand, the establishment is one of the most famous, and reputed to be one of the best managed, on the Continent.

Sir Lowthian Bell* gives the wages of British and American cupola and vessel-men, ours being from 67 to 160 per cent., or on an average 123 per cent., higher than the British. Yet the average wages of all the men at the less slow of the two American mills which he quotes is only 30 per cent. higher than at the British, which certainly seems to imply that a much higher proportion of our men than of the British are unskilled.

If we take the average pay of labourers about the British Bessemer works as $0·70, then the average British Bessemer day's wage of 5s. 11¾d. given by Sir L. Bell is 113 per cent. above that of labourers, while at Mugby Junction the average daily wage is only 64 per cent. above that of the lowest grade of labourers, a fact which strengthens the suggestion of the preceding paragraph.

Turning now to the quantity of labour, *i.e.*, to the number of days' labour per ton of ingots, I must first insist on the extreme caution needed in making comparisons. Not only does the quantity of labour needed vary greatly with the method of working, wholly apart from its swiftness, but the limits of the truly Bessemer labour—the limits of the converting department—vary greatly in different establishments.

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* "Principles of the Manufacture of Iron and Steel," 1884, p. 573.

The consumption of labour may be purposely increased, if a more than equivalent money-saving may thereby be effected in some other respect. Witness the adherence, and even the return, to the use of cupola-metal in this country. So, too, it may, and often does, pay to employ men who are not absolutely necessary, that they may prolong the life of the moulds, bottom-ladles, &c.; or that they may prevent the cracking of ingots, promote regularity, save metal, &c. Liberality in this respect is wise.

Next, the limits of the converting department are a matter of book-keeping; no natural exact limits exist. In comparing the nominally full lists of all the converting-department men given me by some European managers, whose works I have lately visited, with the Mugby Junction pay-roll, I find that from 32 to 38 per cent. of the men classed at Mugby Junction in the Bessemer department are in other works classed outside it. And if we would compare the pay-roll at Mugby Junction with those of some foreign mills using direct-metal we would have to exclude in one case 52 per cent., in another 59 per cent., of the Mugby men.

Among the doubtful classes, included at Mugby, but excluded from the Bessemer department at many other works, are—

1. Those bringing iron, coke, and refractory materials from the stockyards or cars into the steel-works.
2. The superintendents, weighmasters, clerks, and time-keepers.
3. The switchmen, and the locomotive-men, moving moulds, ingots, and bottoms.
4. The men engaged in crushing and roughly preparing the refractory materials.
5. The men at the drop.
6. The enginemen and stokers.
7. The blacksmiths.
8. Those carrying cupola-slag away from the Bessemer department.
9. The machinists and others engaged in current repairs.
10. Those engaged in repairs and other work on Saturday night and Sunday.

With this caution I submit the following statements concerning the labour consumption at American and foreign mills.

In 1876, when our output per pit per 24 hours was about 225 to 250 tons, about 0·67 day's labour yielded a ton of ingots at American Bessemer mills, according to Kupelwieser's data, or 0·64 day's labour in case of the Edgar Thomson works.*

In 1879 the number of days of labour per ton of ingots at one British Bessemer works was 9·47 per cent. greater, and at another 82·14 per cent. greater, than in current American practice, according to data furnished by Holley.†

In 1880, comparing the United States census returns, and the Belgian mineral statistics, Trasenter finds that the annual output of finished product per workman was—

In the United States (Bessemer and open-hearth processes), 82 tons.

In Belgium (Bessmer process), 48 tons.

76 per cent. of the American, and 72·5 of the Belgian output was rails.

According to data collected by Trasenter, apparently in 1884, the number of days of labour per ton of ingots in Bessemer works was as follows:—

	Direct-Metal.	Cupola-Metal.
American—		
Works A, direct, metal	0·41	...
Works B, direct-metal, stokers, blacksmiths, and refractory materials, men excluded	0·267	...
Works C, cupola-metal	...	0·476
Works D, cupola metal	...	0·41
Belgian—		
Direct metal	·3–·4	...
Cupola metal	...	0·4–0·5

In 1884, Sir Lowthian Bell instanced a rather slow and a very slow American Bessemer mill, in which the output per day's labour was 39 per cent. and 9 per cent. less, respectively, than in current British practice; and he seemed inclined to think that our swift work called for great expenditure of labour, though apparently meaning to imply to the reader that these were but impressions, and that his data did not warrant decided opinions.*

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* Trasenter, "L'Industrie Sidérurgique aux États Unis d'Amérique," 1886, pp. 232-236.

† Reports of the Bessemer Steel Company, No. 2, 1880, p. 21.

As the works which he quotes were both slow ones for America, making respectively only 117 per cent. and 65 per cent. of the current British output, their evidence does not bear on the present comparison, which is as to the effect of our very swift running on the consumption of labour.

During the spring of the present year I obtained, from the managers of three British and one Belgian Bessemer works which I visited, what purported to be complete lists of their Bessemer men. They were given from memory, and pretty broad experience has shown me that, under these conditions, the manager seldom remembers all the men; at least, he is almost certain to exclude many who lie near the limit of the converting department, and who are included in the Mugby list.

Throwing out from the Mugby list those men whose duties are quite clearly excluded from the European lists, I find that the days of labour per ton of ingots at the European works exceeds that at Mugby as follows:—

	Per Cent.
At Works A by	0
At Works B by	17
At Works C by	45
At Works D by	11
Average	18·25

The manager of one of the great British Bessemer works gave me, on September 15, 1890, the output and number of men in his Bessemer department. Making a like calculation, I find that the days of labour per ton at his works exceeds that at Mugby by about 13 per cent.

Looking a little further, I find that the difference lies just where we should expect it, in those classes of men whose time is likely to be incompletely occupied in leisurely practice. Such are the vessel-men, much of whose time may be wasted when the blows and the intervals between them are long, the enginemen, the blowers, and the box or stage men. On the other hand, in those classes whose time can readily be fully occupied, even in leisurely practice, such as the stockers, the cupola-chargers, and the pitmen, the economy effected by rapid running is less conspicuous.

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* "Principles of the Manufacture of Iron and Steel," 1884, p. 572.

At the very fast-running American Bessemer works at Middlemarch, in which over 47 per cent. of the *employés* are merely labourers, the labour-consumption during a month of exceptionally great output was only 0·374 days per ton of ingots, when using cupola-metal. In four consecutive months, when using cupola-metal, it was only 0·403 days. In both cases all the doubtful classes already enumerated are included, and the data are most trustworthy. The first is below; the second barely reaches the lower limit claimed by Trasenter for Belgian cupola-metal practice; and my observations in Belgium indicate that a much smaller proportion of unskilled men is employed there than here, and that the usual limits of the converting department there exclude many men included at Middlemarch.

Turning back to three complete pay-rolls from European Bessemer works for 1879, I find that the labour-consumption per ton of ingots then exceeded the present consumption at Mugby as follows:—

	Per Cent.
At Works C (the same works as that styled C just before) by . .	65
At Works E „ „ „ . . .	71
At Works F „ „ „ . . .	130
Average	88·7

I here add some data as to the cost of labour per ton of ingots, though they cannot well be applied to our present question, for lack of definite information as to the relative daily wages.

ESTIMATE OF COST OF BESSEMER LABOUR PER TON OF INGOTS.

American—		
1884.	Trasenter	$1·00–1·75
1889.	Jeansville, cupola-metal, very rapid running, *all doubtful men*, smiths, refractory-men, stokers, &c., and all labourers included; the author	1·185
1889.	Semitopolis, very rapid running, same classes as for Jeansville included, direct-metal; the author	0·95
1889.	Report of United States Labour Commissioner, rail-steel .	1·522
„	„ „ „ „ nail-steel .	1·923
Great Britain—		
1872.	Snelus	$5·11
1879.	Holley, repair-labour included, direct-metal, ...	·82
	„ cupola-metal	·73
1886.	Snelus	·75
1888.	United States Labour Commissioner	·56
1889.	„ „ „	·65

The Continent—

1879.	Holley, half direct-metal	$·67
1889.	Direct-metal, United States Labour Commissioner	·44
„	Cupola-metal	·85

To sum this up, the evidence offered goes to show that the average grade of intelligence needed for rapid running is lower than for leisurely work, agreeing with the results of our *a priori* reasoning. The data given by Holley agree with mine in indicating a decidedly smaller quantity of labour per ton of ingots in American than in European practice; those given by Trasenter on the whole point in the same direction; those given by Bell point in the opposite direction, but they do not represent onr characteristic rapid practice, nor is there evidence that the necessary steps have been taken to make his data comparable among themselves.

From the nature of the case I must expect that many, especially among those with whom prepossession is nine points of belief, will think my evidence far from convincing. If they are familiar with Bessemer practice, and have access to the detailed pay-rolls of Bessemer mills, I ask, or if they prefer, challenge them to compare these carefully with that of Mugby, and to give the world the results as fully as I have.

Quality: is it influenced by fast-running?—Finally, we are told that we sacrifice quality to quantity. There are intelligent and otherwise rational men, safely entrusted with important interests, who go so far as to insist on a necessary relation between quantity and quality, as logically necessary as that between the velocity and pressure obtainable from given energy. These lesions of the power of ratiocination, producing these isolated flings of a mental St. Vitus' dance, and reminding us of the sedate Oriental engaged in calculating eclipses of the moon while he firmly held that they were due to the bite of a dog, should interest the alienist, but are beyond the scope of this paper.

Now, what are the conditions in the Bessemer process on which the quality of its product depends? The proportions of phosphorus and sulphur, of manganese, silicon, and carbon in the steel; homogeneousness due to mixing the recarburizer uniformly with the blown metal, and to preventing segregation; freedom from external cracks, and from an excessive quantity of blowholes.

Phosphorus and sulphur we, of course, leave out of the question. All of these elements that the charge entering the vessel contains will concentrate in the steel, no matter how the process be conducted.

The proportion of carbon, silicon, and manganese depends on the accuracy with which the blower interrupts the blow, on the temperature of the blow, on the accuracy with which the recarburizer is weighed, and on the uniformity as regards oxidising conditions with which it is heated or melted.

Actually the blowing is accurate enough. The proportion of carbon is as nearly constant as the needs of the case require. When greater accuracy is required, as in making soft steel, it is attained without appreciable delay. In a study of the uniformity of our Bessemer practice a few years ago, I found that at some of our rapid works the greatest deviation of the carbon from the average, in a large number of consecutive heats, in a period selected at random, was 0·011 per cent.*

The temperature of the blow is extremely important, affecting not only the composition of the steel, but the soundness of the ingots, and perhaps their homogeneousness. It depends not alone on the composition of the cast iron treated, and the rapidity of blowing, but on the initial temperature of cast iron and vessel. Of these the initial temperature alone is likely to be affected materially by the quantity of the output. The variations in this temperature are due chiefly to variations in the heat lost from the vessel between the blows, and on that lost by the cast iron between the time when it is melted and the time when the blow begins. It seems to me that these variations are likely to be less when the intervals during which they can occur are extremely small, as in our practice, than when, as in more leisurely practice, considerable intervals occur. Indeed, the very fact that, thanks to the extreme subdivision of labour, each man's attention is confined to a very small class of acts, so that he is but a machine, repeating in endless monotony his few stereotyped duties, should foster uniformity. The weighing should be more constant, the conditions of melting the cast iron, of heating the recarburizer, and of teeming, should be more constant than in leisurely practice.

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* *Transactions of the American Institute of Mining Engineers*, vol. xv. p. 347, 1887.

I find it hard to understand how the rapidity of the blow itself should injure the quality of the metal; nor how shortening the intervals between blows should injure it, unless by inducing slovenly casting. To obtain sound ingots, free from cracks and from excessive sponginess, we should teem with care. And here, indeed, one might reasonably fear that our great outputs would lead to unfortunate results.

But rail-steel lies so quietly in the moulds that nothing is gained by teeming slowly. Indeed, in view of the fact that a certain temperature, but slightly above the freezing-point of the metal, seems to give better ingots than either a higher or a lower temperature, and that the steel in the ladle necessarily cools rapidly, it is best to teem rapidly, in order that both the first and the last ingots of each heat may be teemed at as near this best temperature as practicable.

Turning again from deduction to induction, we do not find those specific bad results which might be expected to follow too rapid teeming. The cracks and blowholes to which careless teeming should lead, would in turn lead to physical defects in the rails, due to cracks; hence should result a large proportion of second-quality rails, of cobbles, of rolling-mill scrap. The proportion of second-quality rails is often less than half of 1 per cent. for a month at a time; and even the average of a year may not rise above this amount.* Making any reasonable allowance for our usually easy conditions of acceptance, this certainly indicates a small proportion of cracked or badly-teemed ingots, and reasonable freedom from sponginess.

Again, we are told that, when operations are so rapid, following each other so closely, there is no opportunity to humour the individual peculiarities of each heat, whether in teeming or blowing. Whatever weight this consideration deserves, is, I think, overbalanced by the greater uniformity to which our conditions tend. We do not humour peculiarities, we prevent them. Man after man, each watching the few phenomena under his charge, knowing that he is but a tooth in a wheel, a link in a chain; that his failure to round his little sphere of duties true to the given pitch will so entangle the rest of the vast machine as to lead to prompt and severe punishment; man after man strives to keep the conditions entrusted to him constant. As each is charged with fewer conditions, so can each keep his charge more steady. The uniformity in the carbon-content already referred to is evidence of regularity; so is the small proportion of butt-ingots. In a monthly return before me it is only 1·09 per cent., though the output of the same month broke the record.

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* In works using direct-metal the proportion is usually much higher than this. The yearly returns from one mill using direct-metal show 3 per cent. of second-quality rails; and I have good reason to think that it has been very much higher than this at some mills.

Does the fact that a pair of railway trucks daily delivers one hundred trains instead of two, imply any injury to the quality of those trains, whether as to punctuality, speed, equipment, safety, or comfort?

But how is it, then, that in literature, in art, in designing, beyond a very narrow limit, any increase in quantity of one's product necessarily injures its quality? Without trying to lay bare fully the causes of this difference, I may point to a sufficient and obvious one. The painting, the poem, the design depends for its excellence on the long-continued application of a single human mind, which may, indeed, be assisted mechanically by amanuenses, draughtsmen, &c., but can share the essential work with others little more than the acorn can the assimilation and growth which yield the oak. Teachers, patrons, critics, help the one; the arborator and nurseryman the other. These matters demand the supreme effort of an organism which, from its very nature, cannot exceed a certain speed.

In other matters, as in rail-making, no one of the things to be done needs or is better for prolonged attention, for long time-allowance. Neither rapidity of stocking, of melting, of blowing, of teeming, of carrying to furnace, nor of rolling, need injure. Teeming should be swift: furnacing may be as long as you please, given enough soaking-pits. Despatching a hundred trains daily instead of two does not imply, but rather tends to prevent, slighting any important action: implies such organisation that a vast number of simple acts, each capable of being done at once well and quickly, may succeed each other at brief, exactly-timed intervals.

To what is the particular bent of our practice due? Jointly to the powers of an uncommon man, to favourable conditions, and to the favourable material with which he worked.

The mechanical aptitude which you and we inherit has probably been fostered by the isolation, the ungenerous soil, the inclement climate which the founders of this country braved. Sons of tillers of the wilderness, whose strange, harsh surroundings bade them invent or die, whose scanty tools had to fulfil many purposes, what wonder if mechanical aptitude be one of our strongest characteristics? What wonder if those mobile particles of the mother-mass which such forces as hope of religious freedom or of rapid amelioration of lot, impatience of native restraint, restlessness, sufficed to segregate from those whom the same forces failed to move, have formed, and, immigration continuing, are still forming, a markedly mobile and active race?

Favourable conditions were present in the enormous demand for rails, and in the very easy conditions of acceptance, which led the manager to concentrate his attention more on the quantity than on the quality of his product.

With such material and such conditions, a leader of rare powers, Alexander Lyman Holley, perhaps less by his uncommon mechanical skill than by his hold on the affections of others, and thus by his control over their course, started our Bessemer practice in the path which it has followed. A remarkable group of men, the Fritz Brothers, Jones, Forsyth, R. W. Hunt, joined enthusiastically; traditions, standards, aims, were established lastingly; generous rivalry, *esprit de corps*, free trade in ideas, mutual help, quickness to adopt whatever was good in our neighbour's practice, whether cis- or transatlantic, willingness to give and take.

Beyond the features which I have thus discussed, the following deserve notice:—

General arrangement.—The Holley type of plant has usually been adhered to, with its broad shallow pit, served by at least three ingot-cranes, and with the vessels perched aloft. In the Forsyth modification of this, which several important works have adopted, the vessels stand back from the pit, and the casting-ladle is carried from vessels to pit and back over a short intermediate transfer-track. In this arrangement some 250° of the circumference of the pit are available for ingot-moulds, and four ingot-cranes can be used advantageously. Fig. 2 shows one of our latest and best Bessemer plants.

Cupolas.—The cast iron is usually remelted in cupolas, which, with the exception of a modification introduced at Joliet and whose value is questioned, are very plain but rather large, from 8 to 10 feet in outside diameter and from 14 to 24 feet high from the bottom inside to the charging door. With cold blast at about 10 to 12 ounces per square inch, usually delivered by fan-blowers, but in many works by the positive Baker-blower, these cupolas sometimes run a whole week, but in case of very rapid work they are often dumped every forty-eight hours. Some of them melt as much as 16 tons an hour apiece, on an average of a whole month, with a fuel-consumption which occasionally falls to 1 per 15 of iron melted, or 6·67 per cent. The fuel-consumption for a whole month, when but little steel scrap is melted, is sometimes as little as 1 to 14·3 of iron, or 7 per cent. I am credibly informed that, as a *tour de force*, the coke-iron ratio has been for a whole shift as small as 1 to 20, or 5 per cent.

These large swift-running cupolas have the digestion of an anaconda. Even with this very small fuel-consumption, I have known an ingot weighing 3000 pounds, stuck in a mould weighing another 3000 pounds, to be charged in the cupola, causing no more derangement than if it had been a cambric needle.

This very small fuel-consumption is made possible probably only by the heat generated by the oxidation of the silicon of the cast iron in the cupola itself. Indeed, as much as 0·5, or even 0·6 per cent., of silicon may be thus removed when the fuel-ratio is very small; but, with the common fuel-ratio of 1 to 12, or 8·33 per cent., only about 0·3 per cent. of silicon is removed in the cupola.

Fig. 3 shows a lattice-bound cupola, such as has been built at some important works, but the plain boiler-plate shell is generally used.

In the newer works the ladle which receives the molten cast iron from the cupolas is carried by a locomotive to the vessels, saving running-scrap and the labour of the runner-men.

Direct-metal.—The experience with direct-metal has not been such as to lead to the rapid abandonment of remelting in cupolas. The blast furnace must be so burdened that the least silicious iron made shall still have enough silicon to develop the high temperature needed at the end of the process, at least 1500° C., and that the most sulphurous shall be within safe limits. As the silicon varies greatly and capriciously, it results that some heats have a very great excess of silicon, and that the average proportion of this element must be higher than in cases of cupola-remelted iron. In addition to the disadvantages attending the use of iron rich in silicon already referred to, we have as additional ones sudden variations in the casting temperature and in the proportion of sulphur, leading to increased proportion of second-quality rails, and increased consumption of manganese; variations in the quantity of scrap needed to cool the charge, and consequent increase in the proportion of butt-ingots; increase of converting-works scrap; skulling in vessels and ladles; inaccurate blowing; lessened output; greater consumption of steam; shortened life of bottoms, ladles, moulds, and superintendent. These, in most cases, have seemed to outweigh the obvious saving, which is estimated by different managers at from $0·50 to $1·00 per ton, and which is due to an important saving of labour at blast furnace and cupola, of the coke needed for remelting, and of the loss of iron, silicon, and manganese which occurs in the cupola. Indeed, the greater loss in the converter in direct-metal practice goes far towards balancing the cupola loss in remelting practice.

All these disadvantages attending the use of direct-metal are due to irregularity in its composition. How great this irregularity is, and how much it is lessened by the use of Captain Jones' metal-mixer, is indicated in Table III. Note that the use of the metal-mixer at the Edgar-Thomson Works reduces the range of composition by 37 per cent. and 52 per cent., and lessens the "average deviation from the average" by 43 per cent. and 55 per cent., in the cases of silicon and sulphur, respectively.

Here the mixer has been of great benefit. While it is certainly inconvenient to have even an occasional heat with only 0·68 per cent. of silicon, such heats can be blown, if heat follows heat quickly; while if the ladleful with only 0·364 of silicon had been run into the converter, it could have been got out again only by blowing it on its side, with heavy loss of iron. And it must be admitted that the average proportion of silicon is not much higher, nor is that of sulphur lower, than would be desirable in case the metal were to be remelted in cupolas; nor is the maximum proportion of sulphur so high as to necessitate using more manganese than would be needed in cupola-practice. It certainly seems as if this simple and characteristic device of Captain Jones had turned the balance in favour of direct-metal practice; and it would be far from surprising if all our rail-steel-making Bessemer works were driven to using direct-metal.

TABLE III.—*Uniformity of Blast-Furnace Work, as Deduced from the Composition of Successive Casts.*

		England.		Edgar Thomson.	Edgar Thomson.			
					Successive Casts run into Metal-Mixer.		Same Successive Casts run out of Metal-Mixer.	
		I. Silicon.	II. Sulphur.	III. Silicon.	IV. Silicon.	V. Sulphur.	VI. Silicon.	VII. Sulphur.
Date		February 1890.		June 1888.	June 1890.		June 1890.	
Number of heats represented .	Silicon	29	...	85	108	...	96	...
	Sulphur	...	29	...	...	107	...	106
Average percentage . .	Silicon	2·20	...	2·04	1·336	...	1·186	...
	Sulphur	...	·082	...	...	0·023	...	0·019
Maximum percentage . .	Silicon	4·12	...	3·35	2·613	...	2·103	...
	Sulphur	...	·149	...	...	0·099	...	0·048
Minimum percentage . .	Silicon	1·40	...	0·71	0·364	...	0·684	...
	Sulphur	...	·043	...	...	...	...	trace
Total range of composition .	Silicon	2·72	...	2·64	2·249	...	1·419	...
	Sulphur	...	·106	...	...	0·099	...	0·048
Average deviation from average . .	Silicon	0·328	...	0·497	0·409	...	0·235	...
	Sulphur	...	0·002	...	...	0·0193	...	0·0084

Note to Table III.—I have deduced these numbers from the composition of successive casts at the several works. In the case of columns IV. to VII. inclusive, the compositions given represent 108 ladlefuls filled consecutively at the blast furnaces. The metal was poured from these ladles into the two mixers, and from these mixers it was taken to the converting works, in ladles each of which was filled half from each mixer. Columns VI. and VII. represent samples taken while the iron was running from the ladle into the converter. The mixers were badly skulled at the time, and the manager, Mr. J. Gayley, thinks that later data would yield a more favourable showing. Note that the average proportion of both silicon and sulphur is lower, that of the silicon 0·15 per cent. lower in the converter than in the blast-furnace samples. This has always been found true of silicon, but no previous comparison with regard to sulphur has been made. The removal of so large a proportion of silicon is most surprising.

Vessels.—The tendency has been to increase the size of the vessels. I remember no case in which it has been lessened, while in many cases it has been increased from the old standard size of five to seven, and later to ten, and even twelve and thirteen, tons.

The newer vessels are usually nearly concentric or symmetrical, instead of being retort-shaped, and very large, so that even with rapid blowing very little slopping occurs. The capacity of the newer vessels is from 50 to 65 cubic feet per ton of iron to be blown. With 65 cubic feet per ton there is little slopping; but much trouble from this source has arisen in cases of some new vessels with less than 55 cubic feet capacity per ton.

It has not yet been shown what residuum of real value for special conditions underlies the extravagant and often senseless claims made for the comparatively new patented modifications of the Bessemer converter, such as the Clapp-Griffiths and the Robert. They, or at least the Robert, should yield an unusually high temperature, thanks to the greater loss of iron, and perhaps to the fuller oxidation of the carbon; this would seem to recommend them for small foundries, where but few and small heats can be used daily. The same result may be reached with the common vessel by inclining it, though perhaps less conveniently than with these special vessels.

The vessel is almost always turned by a horizontal rack lying beneath a pinion on its trunnion. The lining is usually rammed in place, but good results have been obtained in the Pennsylvania mills with linings of blocks of mica-schist. The linings in many works are knocked out but once a year, at the time of the general repairs in December, but of course they are patched on Sundays. Thus a lining may make over 30,000 blows.

The bottoms are usually dish-shaped, and in many of them long-shaped bricks or tiles, standing on end and each reaching completely through the bottom, are used. These increase the first cost, but also the life of the bottom, and facilitate drying. The bottoms themselves are usually rammed very carefully, be it with or be it without these bricks, and the mixture used is very dry, barely moist, and fat enough to be balled in the hand; and they are very carefully dried, often for 48 hours. In some works the average life of the bottoms is as much as 28 heats, and single bottoms occasionally last more than 50 heats.

Blowing.—The moment for ending the blow is determined by the eye, and extremely rarely, if indeed ever, by the spectroscope. In making rail-steel it is usual to blow "young;" that is, to interrupt the blow as soon as the first marked shortening of the flame occurs. This course shortens the blow, thus saving time and lessening the consumption of power for blowing, the loss of iron, and the quantity of manganese needed for recarburising.

In making soft steel the blow is, of course, prolonged beyond this point, in some cases till what is locally known as the "second change" appears; that is, till the reddish-grey smoke, which appears about the upper end or point of the flame when it first shortens, and which constantly grows more copious, can be seen along the whole length of the flame, and even at its very base.

The temperature of the blow, while of course controlled in large part by the addition of scrap metal, is in many works further controlled by admitting great volumes of steam along with the blast. This simple trick prevents delays, facilitates making solid ingots closely of the desired composition, and reduces the proportion of butt-ingots to a minimum.

The cranes are always top-supported. Formerly they were usually of the Worthington or so-called Holley type; but of late years the incomparably better Wellman crane has come into general use. Quite a number of these have Mr. H. Aiken's modifications. In several mills these cranes are rotated and their trolley is moved radially by power. The rotation is effected by 3-cylinder hydraulic engines, by friction clutches, and more rarely by racks and pinions. In some, a boy sitting on the crane controls all three movements—the vertical, the radial, and the rotary.

The chief advantage of the Wellman over the Worthington crane is its smaller water consumption. This is due to two things—first, to the smaller weight of its rising parts: the mast may be light, because it receives no transverse stress, this being transferred by the wheels C and D, shown in Fig. 5, to the steel I-beams EE which surround the mast. Again, the mast may be shorter, since it usually need not reach to the top-support. Second, the rise of the rising parts is less resisted by friction again, because the mast receives no transverse stress. This in the Worthington crane and the old Bessemer crane presses the mast against its gland or glands.

The Wellman crane, shown in Fig. 5, is rotated by a small air-engine, driven by air from the Bessemer blowing-engine, and controlled from the pulpit. The water-pressure used is rather low in most cases, but the tendency is now towards higher pressures.

Engines.—The blowing-engines are almost always non-compound, and so are the rolling-mill engines. But, except where fuel is very cheap, this is admitted by many of the more thoughtful to be an error. Compound pumps, however, are used in many works.

The ingots are usually cast from the top, and in unsplit pyramidal moulds. In case of rail-steel they are usually 14·5 inches square, and usually weigh from 1·2 to 1·5 ton each; but at one mill they are 19·5 inches square, and weigh nearly 3 tons each.

The moulds stand in a wide, shallow casting-pit, served by three, and in some later works by four, ingot-cranes. The ingots are very rarely allowed to cool, but are transferred at once from the casting-pit either to common horizontal-hearthed heating furnaces or to Hainsworth pits. These may be likened to Gjers soaking-pits, but with auxiliary gas-firing. Few Americans have been able to grasp the advantage of the Gjers pit. Why we should tie our hands in this matter, and neglect to avail ourselves of that complete control over the temperature of the pit which auxiliary gas-firing gives, few of us can understand. When the ingots come hot enough to the pits, gas and air may be shut off; then the conditions of the Gjers pit are reproduced faithfully. In some of our mills the loss of weight in soaking and rolling, from ingots to rails, is reported to be only 1 per cent., and I have cases taken directly from the records of the mill in which the loss is only 1·5 per cent.

Moulds.—Some managers claim an average life of 100 heats for their moulds, and I believe that the average life for a whole year sometimes reaches 87 heats, when rail-steel only is made. 65 to 70 heats, however, is probably much nearer the usual average life, and in some mills it has been as short as 45 heats. A yearly return before me gives the average life as 70 heats.

The common hydraulic ingot-extractor and the simple one of Mr. T. James are sometimes used; but many object to the former as likely to tear the ingots.

Ladles, &c.—For lightness, the ladles are always lined with loam-sand. In some works their life is only from 10 to 15 heats; in others it rises to 40 and even 50 heats. Stoppers and nozzles last from 2 to 5 heats each; in one mill the average life of the nozzles for a whole month was 7·11 heats. In another case the yearly return from a mill making an enormous output gave the average life of the stoppers as 1·9 heats, and of the nozzles as 6·25 heats. The consumption of refractory materials per ton of ingots was—

	Pounds.
Quartz	22
Clay	16
Sand	21
Old bricks	3
Loam sand	30
	92

0·102 of a tuyere was used per ton of ingots.

Rolling-Mill Practice.—In rail-making the ingots are reduced to blooms about 7 inches square, usually in eleven passes, and almost universally in three-high mills, never under hammers. Cambria has a 48-inch two-high, and Bethlehem a 48-inch three-high, blooming-mill. In the latter the delay in lifting the piece 48 inches has been found considerable: 36 inches is a more common diameter.

The three-high mills usually have the well-known Fritz-Holley lifting feed-tables and ingot-manipulators. Efficient ingot-manipulators by D. Jones, Critchlow and Robinson and Rea, are in use at two-high blooming-mills.

In some blooming-mills noted for their great output only two men are actively occupied; but to these must be added the engineer and spell-hands.

The blooms are further rolled in the older mills to single, in the newer to double or four-length T-rails, usually in eleven passes, and usually after, but in some mills without, reheating. The rail-trains are almost always three-high, usually in two, but exceptionally in three stands, and have two finishing passes. The rolls are usually from 23 to 25 inches, but exceptionally 28 inches in diameter; while one two-high rail-train has a pitch diameter of 32 inches. At some rail-trains with enormous outputs only five men are actively occupied. In addition there are the engineer and spell-hands.

The three-high rail-trains have ingenious and efficient appliances for giving the rail its four motions, rotating it about its axis, raising and lowering it, moving it parallel with the rolls, and feeding it into them.

The plate-mills are usually of the three-high Lauth type, with rocking feed-tables, the upper roll being raised by power, and in many cases by a pair of reversing engines mounted above the housings. Common dimensions for plate-trains are 31 to 32 inches diameter and 100 to 115 inches length. Such mills can roll 175 tons of plates of common sizes in twenty-four hours, with eight men on each of two shifts; say, one roller, one engineer, one screw-man, one feed-roll engineer, two hook-men, and two scale-men.

The universal armour-plate train at Homestead has 20-inch vertical and 32 × 60-inch horizontal rolls, driven by reversing engines 30 × 54 inches and 40 × 54 inches, respectively, and can handle 48 × 54-inch 25-ton ingots. It has a 3000-ton hydraulic shear, served by two pressure-pumps with 65-inch steam and 10-inch water cylinders, and 8-foot stroke. Using steam at 175 lbs. they supply water at 4000-lb. pressure per square inch.

APPENDIX.

PAY-ROLL OF MUGBY JUNCTION BESSEMER WORKS, U.S.A.

DISTRIBUTION OF LABOUR, 1890.

Summary.

Occupation.	No. of Men
Stocking iron	24
Stocking spiegel	10
Stocking coke	8
Stocking limestone	6
Stocking bloom and rail butts	8
Stocking scrap	10
Scalemen	4
Stocking patching, loam, sand, &c.	3
Cagers	14
Sweepers	2
Stage	6
Charging-floor	37
Patching cupolas	5
Melting-floor	27
Vessel-floor	29
Ladlemen	28
Pitmen	63
Cindermen	29
Repair-bottoms	11
Crusher-house	31
Yard labour	25
General labour	68
Switchmen	6
Drop	4
Steel weighers	2
Handling pig iron	...
Boiler-house	6
Blowing-engine room	9
Fan-room	4
Converting building	5
Blacksmith shop for converting works	4
Small locomotives	9
Crusher-house	2
Superintendents, timekeeper, and clerk	4
	503
General repairs, from time of stopping Saturday afternoon till time of starting Monday morning	81

DISTRIBUTION OF LABOUR, 1890.

YARD.	NUMBER OF MEN.				
	1st Turn.	2nd Turn.	3rd Turn.	Total.	Grand Total.
STOCKING IRON.					
Men in charge	1	1	...	2	
Men loading from buggies for chargers	11	11	...	22	24
STOCKING SPIEGEL.					
Men to pile spiegel on buggies	2	2	...	4	
Men additional to break charcoal iron	3	3	...	6	10
STOCKING COKE.					
Men to load coke on buggies	4	4	...	8	8
STOCKING LIMESTONE.					
Men to haul stone from end of run to coke buggies	1	1	...	2	
Men to break, and load on buggies	2	2	...	4	6
STOCKING BLOOM AND RAIL BUTTS.					
Men to load butts for cupolas	2	2	...	4	
Men to load rail butts for vessels	2	2	...	4	8
STOCKING SCRAP.					
Men to load up steel scrap	2	2	...	4	
Men to load up other scrap	3	3	...	6	10
SCALE MEN.					
Men to weigh pig iron for cupolas	1	1	...	2	
Men to weigh spiegel, patching, loam, coal, and general supplies for cupolas	1	1	...	2	4
STOCKING PATCHING, LOAM, SAND, &C.					
Men to fill bins on cupola floor with patching, loam, sand, &c.	2	...	...	2	
Man to fill bins on vessel floor	1	...	...	1	3
CAGERS.					
Men placing loaded buggies on elevator, for the charging and melting floors	7	7	...	14	14
SWEEPERS.					
Men to clear stockers' runway, pick up coke fallen from buggies, and other obstructions	1	1	...	2	2
STAGE.					
Steel blowers	1	1	...	2	
Stage men	5	5	3	13	15

YARD.	Number of Men.				
	1st Turn.	2nd Turn.	3rd Turn.	Total.	Grand Total.
Charging Floor.					
Men to charge cupolas with iron, scrap, butts, coke, &c.	1	1	1	3	
Others, regularly	4	4	4	12	
Additional men, when running fast, at over fifty-five heats	1	1	...	2	
Men to place empty buggies on elevator	6	6	...	12	
Men to charge spiegel	1	1	...	2	
Men additional	1	1	...	2	
Men to run elevators	1	1	...	2	
Men to grease buggies	1	1	...	2	
					37
Patching Cupolas.					
Man to patch cupolas	1	...	...	1	
Men additional	2	...	...	2	
Men additional to help patch cupolas	2	...	...	2	
					5
Melting Floor.					
Iron melters	1	1	...	2	
" "	1	1	...	2	
" "	1	1	...	2	
" "	1	1	...	2	
" " (additional)	3	3	..	6	
Spiegel melters	1	1	...	2	
" "	1	1	...	2	
" " (additional)	1	1	...	2	
Men to weigh molten metal	1	1	...	2	
Men to run elevators	2	2	...	4	
Man to sweep, pick up scrap and carry it to pile	1	...	...	1	
					27
Vessel Floor.					
Men to pour iron from ladle to vessel	1	1	...	2	
Men to pour spiegel from ladle to vessel	1	1	...	2	
Man to patch and line ladles	1	...	...	1	
Men to help patcher, carry coal to vessels and locomotives, take scrap away to pile, and clean up	2	2	...	4	
Vessel men	1	1	...	2	
" "	1	1	...	2	
" "	1	1	...	2	
" "	1	1	...	2	
Runner men	1	1	...	2	
" "	1	1	...	2	
Men for heavy scrapping	1	1	...	2	
Test boys	1	1	...	2	
Men to sweep and clean floor	2	2	...	4	
					20

YARD.	Number of Men.				
	1st Turn.	2nd Turn.	3rd Turn.	Total.	Grand Total.
Ladlemen.					
Ladlemen to set stoppers	1	1	1	3	
Men to be with ladle when pouring heat	1	1	1	3	
Men to patch and put in nozzles	1	1	1	3	
Men to help	1	1	1	3	
Men to clean nozzles	1	1	...	2	
Men to catch tests	1	1	...	2	
Men to help patchers	1	1	...	2	
Men additional in hot weather	1	1	...	2	
Stopper-maker	1	...	...	1	
Man to help	1	...	...	1	28
Pitmen.					
Men in charge of pit	1	1	1	3	
Men in second charge	1	1	1	3	
Other pitmen	8	8	8	24	
Helpers	1	1	...	2	
Steel-pourers	1	1	...	2	
Men to swing ladle	3	3	...	6	
Men to swab moulds	2	2	...	4	
Men on dog-house	1	1	...	2	
Boys to cool moulds	2	2	...	4	
Boys to catch tests	1	1	...	2	
Men additional in hot weather, to help cranemen	1	1	...	2	54
Cindermen.					
Men to carry slag from vessels	1	1	...	2	
,, ,, ,, ,,	2	2	...	4	
Men to carry slag from slag pitmen	3	3	...	6	
Cupolas cindermen	4	4	...	8	
Men to keep spiegel slag running clear	1	1	...	2	
Cartmen	7	...	...	7	29
Repair Bottoms.					
Foreman bottom-maker for vessels (total tonnage)	1	...	...	1	
Men to make bottoms	1	1	...	2	
Men to help	1	1	...	2	
,, ,,	2	2	...	4	
Men to line new ladles	1	...	...	1	
Man to help	1	...	...	1	11
Crusher-House.					
Man to mix materials for bottoms and vessels	1	...	...	1	
Men to help	5	...	...	5	
Men to mix for cupolas	3	...	...	3	
Men to attend to the grinding	1	1	...	2	
,, ,, ,, ,,	2	2	...	4	
Men additional	1	1	...	2	
Men to attend to crusher	1	1	...	2	
Men to break quartz	1	1	...	2	
Boy to dry clay	1	...	...	1	
Boys to dry clay	3	...	...	3	
Men to attend to carts	6	...	...	6	31

YARD.	Number of Men.				
	1st Turn.	2nd Turn.	3rd Turn.	Total.	Grand Total.
Yard Labour.					
Foreman	1	...	...	1	25
Men to handle and unload scrap, loam, tuyeres, clay, sand, spiegel, &c.	21	...	...	21	
Men to pick scrap at dump	3	...	...	3	
General Labour.					
Foremen	1	1	...	2	68
Labourers to change bottoms, clean shop, &c.	15	15	...	30	
Men to handle hot ingot butts, change moulds, &c.	10	10	...	20	
Rigger to repair building, clean stacks, and repair buggies	1	...	...	1	
Man to help	1	...	...	1	
Men to clean under the vessels, and carry scrap to pile	3	3	...	6	
Men to keep track clean from vessels to bottoms	1	1	...	2	
Men to clean shop	1	1	...	2	
Men to grease buggies	1	1	...	2	
Men to clean tracks and coal locomotives	1	1	...	2	
Switchmen.					
Men to attend the engine in handling hot and cold moulds, to carry scrap from rail mill to converting department, and drop	1	1	...	2	6
Men to attend locomotives in carrying hot ingots to rail mill	2	2	...	4	
Drop.					
Man to break up skulls, old moulds, and scrap	1	...	...	1	4
Men to help	3	...	...	3	
Steel Weighers.					
Men to weigh steel	1	1	...	2	2

YARD.	Number of Men.			
	Day.	Night.	Total.	Grand Total.
Boiler House.				
First firemen	1	1	2	6
Second „	1	1	2	
Water tenders	1	1	2	
Blowing-Engine Room.				
First engineers	1	1	2	9
Second „	1	1	2	
Third „	1	1	2	
Fourth „	1	1	2	
Men at pressure pumps	1	1	2	

YARD.	Number of Men.			
	Day.	Night.	Total.	Grand Total.
Fan Room.				
Engineers	2	2	4	4
Converting Building.				
Man in charge of machinery	1	...	1	
Handymen	1	1	2	
Greasers	1	1	2	5
Blacksmith's Shop for Converting Works.				
Blacksmiths	1	1	2	
,, helpers	1	1	2	4
Small Locomotives.				
Engineers	1	1	2	
Engineer	...	1	1	
,, handling ingots	2	2	4	
,, ,, moulds	1	1	2	9
Crusher House.				
Engineers	1	1	2	2
Superintendents, Timekeeper, and Clerk.				
Superintendent	1	...	1	
Assistant superintendent	...	1	1	
Timekeeper	1	...	1	
Clerk	1	...	1	4
Total				503

[General Repairs.

GENERAL REPAIRS FROM THE TIME OF STOPPING ON SATURDAY AFTERNOON TILL THE TIME OF STARTING ON MONDAY MORNING.

YARD.	NUMBER OF MEN.				
	1st Turn.	2nd Turn.	3rd Turn.	Total.	Grand Total.
CHARGING FLOOR (patching cupolas).					
First patcher	1	...	...	1	
Second „	1	...	...	1	
Third „	1	...	...	1	
Labourers additional	2	...	...	2	5
MELTING FLOOR.					
Men knocking out skulls, relining same, and putting in tuyeres	3	...	...	3	
Men knocking out skulls from vessel runners and relining same	2	...	...	2	5
VESSELS.					
First vesselman to patch	1	...	...	1	
Second „ „	1	...	...	1	
Third „ „	1	...	...	1	
Fourth „ „	1	...	...	1	
Labourers to help	8	...	...	8	
Vesselman at night to light up	1	...	...	1	13
TOOL-HOUSE.					
Tool-keeper by day	1	...	...	1	
Tool-keeper by night	1	...	...	1	
Man to watch in bottom-house, Saturday night	1	...	...	1	
Sunday	1	...	...	1	
And Sunday night	1	...	...	1	5
GENERAL LABOUR.					
Foreman	1	...	...	1	
Men to clean shop	4	..	...	4	
Labourers to clean dumps, clean shop, make ready to light up, help repair machinery, change moulds, and do whatever is necessary to put things in shape	45	...	...	45	50
CLEANING VESSEL STACKS.					
Rigger to clean the vessel stacks when clogged with cinder	1	...	...	1	
Others to help	2	...	...	2	3
Total					81

DISCUSSION ON MR. HOWE'S PAPER.

Mr. Percy C. Gilchrist opened the discussion, observing that to Europeans the very low silicons which had been given on page 99 of Professor Howe's paper were extremely interesting. So far as he was aware, with the exception of Sweden, they were not able in Europe to produce steel successfully if they used silicon as low as 0·6 to 0·9. They had silicon as low as that in the basic Bessemer, but then they had phosphorus present besides. They could not make Bessemer steel with a pig of that composition, and get it into the ladles, much less into the ingot, but he supposed that it was done in America by their attention to small details and by the blows following each other quickly. The very low silicon that they used largely explained how such quick work was possible. If they could get the stuff into the ingots, it would be utterly impossible to make bad steel with ordinary care. As they all knew, the only trouble in making acid steel was the high silicon. If they had high silicon, they required great judgment in the matter of scrapping or blowing the steel, so that it should regularly contain the same amount of silicon. When they had only 0·6 to 0·9, they could not leave any silicon in, and therefore if they got it into the ingot moulds (and that was a big "if"), it must be good, because they had only to add, at the completion of the blow, a small amount of ferro or spiegel—which was a very simple thing—in order to give them a regular amount of carbon and manganese. Therefore, for any one to say that because they worked quickly they must necessarily make bad steel, he thought, was simply absurd on the face of it. The mixer, as described, he thought, would be extremely useful to them in England. At one of the works that he was connected with, they had tried to use pig iron direct from the blast furnace for the basic Bessemer, and they had given it up, because in spite of the regularity which the blast-furnace managers told them they had obtained, they did not find that they got the pig iron direct from the furnace sufficiently regular in composition to give them the best results in the matter of yield. For example, it paid them at those particular works to re-melt all the pig iron, simply because, by re-melting it, they got the least "defectives" and the best yield. The reason of the better yield was very simple. If they had got a pig iron that varied much in silicon, the after-blow would vary with the silicon, and by mixing the pig iron and re-melting it in the cupola, they got absolutely regular material running into the converter, and the blow would always be of approximately the same duration. The blowers should know that the next blow would require an after-blow of about the same duration as that required by the previous charge. They must arrange them on the Monday morning, so that the material could be kept the same all through the week. They ought to pay special attention to the Jones mixer, to which reference had been made. The last point to which he would refer was the question of blowing in steam. This was specially interesting to basic people, and for this reason: As they knew, in the basic Siemens process they got rid of the phosphorus before the carbon was gone. If they could get rid of that after-blow, they would save from 3 to 4 per cent. in yield; and although they could make good material now, they would make even better with no after-blow. Therefore, any man who discovered how to do away with the after-blow would do one of the three things required to make the basic process perfect. It had always occurred to him that the reason why an after-blow was required was that they were not able to get base and oxygen simultaneously offered to the phosphorus. In the basic open-hearth furnace they gave oxygen and base at the same moment, and they got rid of the phosphorus before getting rid of the carbon. In the basic Bessemer process they were unable to give a base until the carbon had gone. If some one would discover some vaporous or liquid base that could be blown in with the blast, then that person would do one of the three things required to make the basic process perfect.

Mr. William Tozer (Sheffield), said: The experience which I have had in the basic Bessemer practice has been principally in the direction of the higher qualities of Bessemer steel which are used in the Sheffield district; and in studying Professor Howe's paper it has occurred to me that if we could obtain a Bessemer hæmatite pig iron which would run lower in silicon than the iron that they offer us in the market, it would be a great advantage to us for certain classes of Bessemer steel. I allude to a silicon probably not so low as the American practice, but if we can obtain an iron with 1·0 per cent. or something of that sort, it would be a distinct benefit to us. As it is now, if we require anything of the kind, we have to either use No. 3 or No. 4 hæmatite, which is pretty high in sulphur, for our purpose. I don't know whether the sulphur could be reduced by increasing the manganese. I suppose, if that were done, the cost would be increased at the same time. I think that our very high silicon irons are not at all suitable to the high quality of Bessemer steel which is made in several districts of our own country. There is one thing that struck me with reference to the enormous output. I think, if in our own country we were able to make anything like the wonderful output which has been mentioned by Mr. Howe, that about five of our rail-works would be all that would be necessary. I simply mention this to show that in America you have a stimulus for increasing your output because you have a market which is always getting larger and larger; whereas in our own country we have about fifteen rail-works, and if we were able to do anything like what you are doing here, I think we should only want about five. I should be interested if Professor Howe would inform us whether the men here work three shifts of eight hours or two shifts of twelve hours. He does not mention that in the paper. It would be very interesting, because it struck me that the men must be very hard worked to get the large turn-out. He also mentioned that the way of calculating wages in England is not the same as has been adopted in this country. I can only say that, as far as Sheffield is concerned, and the district there, we always include the wages of every man connected with the Bessemer department in arriving at the cost of our ingots. I mean the stock men in the pig yard, the boiler feeders, engine tenders, and so on. Mr. Howe has mentioned in his paper that that did not appear to be the custom at the works where he had had facilities for making investigation. I was very much surprised to learn that, for it certainly is the custom in the district that I represent.

Mr. William F. Durfee said it was well known to American engineers that he was responsible for the engineering of the works at Wyandotte. It was also well known that those works were abandoned after a few years of experimental existence. They were only intended as experimental works; they had accomplished their purpose, and in those works were made the ingots from which the first steel rails rolled in that country were produced. Those rails were of admirable quality; they went into one of the North-Western roads, they were used up after many years of service; and he believed that at the present day there was only one fragment of the rails in existence. He had had the pleasure of seeing that fragment a few years ago mounted by his friend, Mr. Potter of Chicago, and preserved in a very elegant case. He was not going to detain them by speaking at any great length. He should, however, be glad to contribute to the Institute *Journal* some matter describing these early works, and giving the reasons for their abandonment. Those works were intended simply as an experiment on a grand scale to practically test the question whether from Lake Superior ores, or from other American ores and metals, a satisfactory steel could be produced. At those works was erected the first laboratory, he believed, that was regularly operated in connection with an iron and steel works in America. Any one who wished to ascertain precisely what was done there could do so by reference to the "Transactions of the American Society of Mining Engineers."

It was the intention of those who furnished the means for carrying on those experimental works that the moment it was satisfactorily demonstrated that steel could be produced of proper quality, they were to proceed with the erection of larger works, in which the business could be prosecuted on a manufacturing scale. When that time arrived, they were not prepared, or they declined, to proceed in the way that had been agreed upon. He immediately resigned his position, and the attempt was then made, under other management, to develop the experimental work by putting in a second converter into a manufacturing establishment—a thing which he pronounced at the outset to be utterly absurd to undertake; and after one or two years of very unprofitable existence, the attempt proved a failure in a commercial sense, though there was a great deal of good steel made there.

With regard to the apparatus, when he designed that original apparatus, the steel that was made in England was being blown with only 8 lbs. pressure, and they had nothing else to go by in America; but he reasoned, from a study of the subject at that time, that it would be very much better if the pressure was increased. As a result of that reasoning, he designed an engine for blowing 16 lbs. pressure of blast. At that time the highest pressure in use in America for any metallurgical purpose was 7 lbs. for a blast furnace. That engine answered its purpose; it blew the 16 lbs. successfully. It was used throughout all the operations there, and finally, he presumed, it went into the scrap-heap, simply because it was not up to the pressure which was found to be desirable. But he was firmly persuaded, after a few blows, that the movement towards an increase of pressure was a mistaken one, and he was just as much persuaded at the present moment that the ponderous engines that had been designed to produce 20 and 25 lbs. pressure were a totally unnecessary expenditure of capital, and that equally good results could be obtained with a much more moderate pressure.

Mr. H. M. **Howe** said that some of the shifts were of eight, and some of them were of twelve hours. In Appendix A. was given a full statement of the number of men, and in that was indicated, for each class of men, whether there were two or three shifts—that was to say, whether they were eight or twelve hour shifts. They were ruled off into first, second, and third turns. Where only the first and second turns were included, that meant that there were only two shifts. Where there were first, second, and third included, that meant that there were three shifts of eight hours each. As to the limits of the Bessemer department, he thought the gentleman was hardly correct, speaking generally; though doubtless as to his own district he knew perfectly. He could not just say how it was in the books of the establishments, but as the total number of men had been given him by the managers of Bessemer departments in Great Britain, there were between 32 and 38 per cent. of the men in the Bessemer department who were classed outside. Finally, as to Mr. Durfee's view as to low pressure (communicated through the Secretary), had Mr. Durfee's connection with our Bessemer industry been longer, his strong personality might well have left on it an impress comparable with that of the men whom he had named. Their whole system depended upon extremely rapid blowing. The oxygen taken up by the iron must be taken away from that iron before the iron got to the top of the bath. They had air blown in at the bottom of the bath, and the iron became oxidised by the air, which passed up very rapidly. The depth of metal above where the blast came in must be so great as to enable the iron in travelling up to become deoxidised before it reached the top of the bath. The blast must travel a long distance through the bath in order to accomplish that. The distance which it must travel to permit that must, of course, increase with the rapidity of the blowing. If blowing slowly, a shallow bath might suffice to deoxidise the iron; but with large outputs, and blowing rapidly, they must have a deep bath. If they had a deep bath, they must have high pressure, as Mr. Durfee knew quite well.

On the motion of the President, a vote of thanks was given to Mr. Howe.

CORRESPONDENCE.

Mr. **James Gayley** (of the Edgar-Thomson Steel Works) writes: At the Edgar-Thomson Works the practice is to use iron containing a small proportion of silicon. The average content of silicon in the metal, as it is poured into the vessels, is 1·10 per cent. As all of the metal first passes through a metal mixer, a considerable quantity of the initial heat is lost, but in cases where the iron is sent direct to the Bessemer department, *i.e.*, without passing through the mixer, it is found that 0·80 per cent. silicon will give the same result as to temperature of bath. For rapid working, low silicon metal is not only a necessity, but it avoids, to a great extent, the scrapping of the heat in the vessel, which is an uncertain operation. The low silicon iron spoken of is not, as is very often considered, a synonymous term for high sulphur iron. As a matter of fact, the average sulphur in our iron, ranging from 1·00 to 1·30 per cent. silicon, is lower than when the silicon is 2·00 to 2·30 per cent. This is what might naturally be expected, inasmuch as the low silicon metal requires a less quantity of coke for its production; and as, in our case, the sulphur is derived entirely from the coke, there is a less quantity to be got rid of.

The grade of metal is in no wise deteriorated by keeping the silicon low; iron containing 1·00 per cent. silicon being as open grained as that containing 2·00 to 2·50 per cent.; in fact, it is quite common to see a high grade of 1 inch iron with only 0·80 per cent., and even with silicon as low as 0·65 per cent. the metal is grey and has a good grain. It frequently happens that the Bessemer department will run for twelve hours on metal which will not exceed 0·70 per cent. of silicon, although the result from such metal is not as good as when silicon is higher.

Mr. JOHN FRITZ (of the Bethlehem Iron Company, Pennsylvania) writes: The American Bessemer practice outlined in Mr. Howe's paper is framed upon facts readily accessible at our different works; and knowing him to be thoroughly efficient as a discriminating collector of such material, I have every confidence in his presentation of the case, especially since such facts as come within my own personal experience I find correctly stated.

The question raised as to the low silicon percentages used at one or two of our works, arises mainly, I think, from a want of familiarity with the close and accurate methods that obtain in the driving practice of these works.

Our own practice is by no means so rapid, and our pig is comparatively free from manganese; and yet, melting with anthracite in place of coke, we find no difficulty in working iron of 1·10. This we vary to as high as 1·50 to suit the conditions of different steels varying in carbon from 0·06 to 1·25.

Melting with anthracite is by no means so rapid as with coke, but preference is given to it owing to the lower and much more regular content of phosphorus and sulphur. All anthracite for cupola-melting is carefully selected from one or two mines, and frequent analyses are made in order to avoid, as far as possible, any variation.

Mr. E. C. POTTER (Chicago) writes: While I believe that the general average of American Bessemer pig iron, as delivered to the converter, is lower in silicon than the established European practice, yet it seems to me that Mr. Howe has given undue prominence to practice which uses pig iron exceptionally low in silicon, thereby unintentionally misleading his readers as to the usual and average American practice. Even the practice which he cites, as using iron with silicon considerably below 1 per cent., is not the ordinary or average practice at the works in question. If I translate Mr. Howe's cipher names of works correctly—and in this particular case I believe I do—the use of iron as low in silicon as stated, is, I believe, largely confined to those occasions of "beating the record," for which these works have achieved a considerable notoriety. For these occasions, in order to attain the greatest possible speed, a sufficient quantity of low silicon iron is selected out of stock, and reserved for this great effort, which extends over periods varying from a week to a month. In this way, certainly, many consecutive heats, and even many consecutive days, of very low silicon practice may be obtained. But when the record has been sufficiently broken, a return to the ordinary stock of iron is necessary, the average of which is considerably higher in silicon because of the withdrawal of all the low silicon iron. I have known of these works being compelled to run largely on iron carrying 3 per cent. to 4 per cent. of silicon after a month spent in "record-breaking." Their average, therefore, is no lower than the rest of the country, which I should place at 1·75 per cent. to 2·00 per cent. of silicon. It is impossible for any works, or any group of works, to run continuously on iron below 1·00 per cent. in silicon, simply because it is impossible for any blast furnace to make this character of iron regularly and uniformly, and of sufficient purity, especially as regards sulphur, for steel-making. I would not be construed as condemning the use of low silicon iron, or controverting Mr. Howe in his general deductions. I merely desire to correct what seems to me to be an unintentionally misleading impression to the reader of his admirable paper, that the usual or typical American practice is the use of this very low silicon iron.

Upon one point, however, I must squarely take issue with Mr. Howe—namely, on the question of rapid running as affecting quality. Upon the general proposition that of two plants of equal size, one American, the other European, the former will yield a considerably larger tonnage than the latter, and in that respect is a "rapid" plant, I am firmly of the opinion, with Mr. Howe, that our quality does not suffer with the larger output, for reasons clearly set forth in the paper under discussion. But when a plant which, for example, would make 700 tons per day in Europe, or 1000 tons per day in America, is forced in America to make 1200, 1400, or even 1500 tons per day, I insist that the result as regards quality is unsatisfactory, not to say disastrous. I am speaking now of that strictly American practice of "beating the record." The utter recklessness with which operations are carried on on these occasions is sufficient proof that the results must be bad—and they *are* bad. I never knew of a record broken in which the record for high percentage of second quality was not also broken. The desire for tonnage, tonnage, nothing but tonnage, by both manager and men, leads to slovenly, careless work. In the mad struggle for supremacy everything goes with a rush—scrapping carelessly done; blowing more or less inaccurate; heats poured hurriedly and in a slovenly manner; nozzles in ladles badly set and imperfect streams resulting; moulds carelessly and irregularly set in their stools, causing large "fins" on the bottoms of ingots; moulds insufficiently cooled; and ingots stripped too soon. Any or all of these deficiencies would seriously impair the quality of the product. Then, when the rail-mill is reached, we find the steel either insufficiently heated or scorched; the rolls are not changed as soon or as often as they should be; saws are allowed to run until dull, resulting in rough and inaccurate cutting; rails are straightened so hot that they cannot be handled without hand-leathers, consequently they continue to warp after they have left the mill, reaching the purchaser's hands in bad condition, and often unfit to lay in track. It is in the finishing department of the mill that the sins of "beating the record" are most largely developed. A hot-bed designed to deal with 1500 rails per shift cannot well deal with 2000 rails per shift with equal care. There are two ways of meeting the emergency of a heavy surplus of rails on the hot-bed: one, to pile the surplus of rails, unstraightened, in the yard, to be straightened when not engaged in "beating the record," which is expensive and not particularly good for the rails; another way is to *cool all the rails on the hot-bed with water*, which certainly facilitates matters, but cannot be recommended as good or safe practice. It has actually been done, though, at a works noted for its "distinctive American practice," use of low silicon pig, and frequency of "beating the record." It is unnecessary to add that these rails so cooled were not popular upon the railway for which they were intended, the manager of which railway was singularly unappreciative of the necessity for "beating the record." These same works, after a month's run, in which the records for the month, week, day, and shift were hopelessly smashed, and the works and its manager surrounded with a halo of glory, took *three months* to straighten and ship the surplus of rails piled in the yard, working Saturday nights and Sundays. During that time the accounting department were entirely in the dark as to whether certain contracts were filled, or where they stood with their orders.

There is one individual about the plant who does not enter upon a "record-breaking" spurt with the same enthusiasm as his co-labourers. This is the master-mechanic. A broken record has no charms for him. He knows who will have to "pay the fiddler," and thirty-six hours of steady hard work on his machinery to get it in any kind of shape for the following Monday morning is not alluring. He is the man who is compelled to beat all kinds of records to get ready for next week, and he can testify feelingly that our machinery *does* suffer by reason of the over-driving incident to "beating the record."

This is a cursory glance at some of the salient features of this peculiarly American institution, whereby many managers gain renown for themselves and their works. I fail to see any features in it to commend it to universal practice. It simply is a "spurt," by which a rate of speed is attained that could not be continued, and would not be if it could. The manager, therefore, has not proved anything as to his capacity, and has simply succeeded in deteriorating the quality of his product to gratify a foolish and eventually extravagant pride. What, then, is there to praise? I believe most heartily in the spirit of emulation and *esprit du corps*, which is so important a factor in the successful management and operation of our works, but I believe these things should be tempered with reason and good judgment.

Mr. H. M. Howe has replied on the correspondence as follows:—Mr. Potter's strictures demand a very full reply. In speaking of the Ningunaparte practice of having but from 0·6 to 0·9 per cent. of silicon in the whole vessel-charge as "most characteristically American," I thought that the immediately preceding clause, stating that in the majority of American mills the vessel-charge had less than 1·75 per cent. of silicon, made it clear that by "characteristically American" I did not mean usual. The percentage of silicon at Ningunaparte is decidedly lower than at most American mills.

That I have given the Ningunaparte practice undue prominence I cannot admit. It is one of those clouds like a man's hand, whose importance is not readily overrated.

The latest information which I had received from the officers of Ningunaparte gave their usual silicon-content as between 0·6 and 0·9 per cent. It is still their favourite practice; but as it is not always convenient to obtain iron with so little silicon, and as, owing to temporary delays, it is sometimes desirable to use a little more silicon, the average proportion of silicon taken over long periods is a little higher. The last returns which I now have, covering a period of nearly a year, give the average proportion of silicon for the whole period as a little less than 0·98 per cent., 10 per cent. of all the heats having less than 0·73 per cent. of silicon.

The Bessemer superintendent writes me (March 1891), "I should have had it lower if I had had the low-silicon pig to melt; as it was, I was obliged to use all kinds of scrap to keep it down."

He states, further, if the rail-mill would take the steel as fast as he could make it, he could run continuously with from 0·66 to 0·76 per cent. of silicon in the molten metal—I believe further reducing its effective calorific power, by charging in addition cold steel scrap, and blowing steam through the bath.

As far as the calorific power of the charge is concerned, the above average of 0·98 per cent. of silicon is equivalent to an average probably of less than 0·90 per cent. of silicon in the case of charges wholly melted before their introduction into the vessel; for about 4 per cent. of the charge is introduced in a cold state into the vessel; and a great deal of steam is blown through the charge to lower its temperature. By like reasoning the average silicon-content of the first four months of 1890 at the Union Mill, as given in Table IV., is equivalent to an average of about 0·85 per cent. of silicon in the case of wholly molten charges.

I will now take up some of Mr. Potter's statements in detail.

1. He states that the average silicon-content at Ningunaparte is not lower than from 1·75 to 2·00 per cent. He is misinformed. I have just given the average for a period of nearly a year as less than 1 per cent.

He says that *the average silicon in other American works is from* 1·75 *to* 2·00 *per cent.*

I had stated that the majority of mills use less than 1·75 per cent. I have before me information from seventeen American Bessemer works, including all the principal ones.

Number using less than 1·30 per cent. of silicon	7
Number using less than 1·75 per cent. of silicon	13
Number using more than 1·75 per cent. of silicon	4

My information from those using more than 1·75 per cent. of silicon is, with one exception, some years old, and it is not unlikely that some of these have followed the general current of American practice, and reduced their silicon. Messrs. Fritz and Gayley have just given you the practice of Bethlehem and Edgar-Thomson.

Mr. Potter may be misled by taking as the silicon-content of the vessel-charge that of the pig iron used. This, however, is first diluted by the addition of scrap before melting in the cupola, then impoverished by the removal of silicon in the cupola, and finally further diluted by the addition of cold scrap in the vessel itself.

2. He says, *It is impossible to run continuously with less than* 1 *per cent. of silicon, because the blast furnace cannot make iron with so little regularly, and free enough from sulphur.*

Mr. Gayley has only just told us that the average silicon-content of the Edgar-Thomson metal (direct metal, I take it), as it goes to the vessel, is 1·10 per cent. If this metal were to be remelted in cupolas, as in common American practice, and if the manager sought to bring the silicon-content of his vessel-charge continuously below 1·00 per cent., he could certainly do it by so mixing the iron that each charge would have nearly the average composition of the metal from the blast furnace, or 1·10 per cent. If, now, the metal further lost 0·20 per cent. of silicon in melting in the cupola, and if to the melted charge 8 per cent. of scrap bloom and rail-ends were added, the silicon in the vessel-charge would be only 0·83 per cent. Mr. Gayley further tells us that at Edgar-Thomson the sulphur decreases with the silicon, instead of rising, as Mr. Potter implies.

But the loss in the cupola is often greater than I have here taken it, and the proportion of scrap to be remelted may be higher; so that it should be wholly possible, under such conditions (I do not say convenient), for the Bessemer manager continuously to obtain in practice vessel-charges even lower in silicon than 0·83 per cent., if he sought them.

3. Admitting that reasonably rapid running does not injure quality, Mr. Potter takes issue squarely with me, insisting that record-breaking efforts injure quality. This is quite a feat, as I had never intimated that they did not. Then follows a vigorous denunciation of record-breaking, and of the Ningunaparte record-breakers. To make sweeping charges against a class of men is easy; to rebut them in detail necessarily difficult. To prove a negative is rarely easy. Many of Mr. Potter's charges cannot, in their very nature, be disproved. Mr. Potter himself has been a notorious record-breaker. I find it difficult to believe his charges, even as applied to himself. As I have no interest, beyond a love of truth, in collecting evidence to free other record-breakers from his charges, and you none to hear detailed evidence in rebuttal, let it suffice if I insist generically that his picture of what occurs during record-breaking is, as regards those record-breaking mills with which I am familiar, including Ningunaparte, most grotesquely and unrecognisably exaggerated and distorted; and if, replying specifically, from such evidence as is at hand, I meet with exact numerical data enough of his unsupported assertions to give the reader some idea of their credibility, and of the care exercised in their preparation.

Mr. Potter never knew a record broken which did not also break the record for high percentage of second-quality rails. I know many, indeed, where, as at Edgar-Thomson, the rails are chipped between the passes at the rail-train, and where every bloom that even gives the least promise of producing a second-quality rail causes serious delay, while its incipient cracks are chipped out. It is evident that, if the output of rails is to be great, the proportion of second-quality rails must be small. That this is true, witness the fact that the greatest "runs at these works have been made when the percentage of 'second' has been lowest," as I am assured (March 4, 1891) by the most unquestionable authority. Witness the statement of Captain Jones, at the time general manager of these works, that "it is impossible to attain great speed in working while making bad steel." *

At the Union Works the proportion of seconds for the months of November 1887 and May 1888, both of them, I believe, record-breaking months, was 1·53 per cent. and 1·42 per cent., respectively; by no means excessive. I have known mills to make over 10 per cent. of second-quality rails when running at moderate speed.

The output of the Union Works for several of the seventeen consecutive months represented in Table IV. breaks almost all records existing prior to the first of them. If there were any necessary connection between the output at these great speeds and the proportion of second-quality rails, it should be apparent in this table. Yet it gives no such indication. Confining ourselves to the last eleven months, May, the slowest but one, has 60 per cent. more seconds than the average. The average proportion of seconds for the fastest six months is actually less than that for the slowest five months.

5. He says that, *in record-breaking scrapping is carelessly done.* Careless scrapping implies irregularity in the weight of the charge, and hence an excessive proportion of butt-ingots, *i.e.*, of pieces of ingots which fall below that weight needed for making an aliquot whole number of rails. Yet in the banner month of October 1889, at the Union Works (cf. Table I.), so far as I know still the champion month for the whole world, the proportion of butt-ingots was only 0·47 per cent. of the total weight of metal charged. If this be madness, there's method in it.

So, too, the average proportion of butt-ingots in the last eleven consecutive months in Table IV., all of them high-speed months, was only 0·66 per cent.

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* *Journal of the Iron and Steel Institute*, 1881, I., p. 137.

6. He says that *in record-breaking the blowing is more or less inaccurate.* So it is; decidedly less inaccurate than to justify his apparent implication. Turning again to the last eleven months, Table IV., we find that the variation in the proportion of carbon in the steel is actually less in the fastest six than in the slowest five months. That is to say, with the irony of fate, the rapid work here, even at this tremendous pace, had more accurate blowing than the relatively slow work.

During the famous month of October 1889, at the Union Works, the carbon in the steel lay, with the exception of a single doubtful heat out of the (about) 3600 heats, within a range of 0·06 per cent. above, and 0·07 per cent. below the average. Considering the large number of heats represented, considering that, in order to save iron, it is desirable to arrest the blow at the first marked indication of shortening of the flame, is this more, or is it less inaccurate blowing?

Now, does this inaccurate blowing, which, Mr. Potter says, arises during record-breaking, consist in blowing sometimes too long and sometimes not long enough? In that case the insufficiently blown heats would give steel which would be too hard, and the resulting rails should either be classed as of second quality or rejected. But, as we see elsewhere, there is no indication of an excessive proportion either of second-quality rails or of rejected rails.

Or does the inaccurate blowing consist solely in sometimes blowing too long? In this case the loss of iron should be excessive. Yet, in the banner month of October 1889, at the Union Works, the loss was only 10·85 per cent.; the average loss for the last eleven rapid months of Table IV. was only 9·60 per cent.

Finally, inaccurate blowing should cause irregularity in the weight of the blown charge, with consequent increase in the proportion of butt-ingots; yet we have seen that this proportion is so insignificant as to indicate extreme accuracy in all the conditions affecting the weight of the blown metal, whether as to weighing, blowing, or pouring.

7. He says that during record-breaking *the steel is poured hurriedly and in a slovenly manner; the nozzles are badly set, causing imperfect streams; the moulds are irregularly set, so that large fins form on the bottoms of the ingots.* If this is true, it

should manifest itself by increasing the proportion of second-quality rails, of pit-scrap, and of butt-ingots. If the pouring is irregular, the weight of the ingots must vary, and hence a considerable weight of butt-ingots must arise. We have seen that their weight is inconsiderable.

Actually only 2·30 per cent. of scrap altogether was made in the month of October 1889, at the Union Bessemer Works, of which 2·21 per cent. was pit-scrap, and 0·09 per cent. was iron scrap. So, too, in the last eleven consecutive rapid months given in Table IV., only 2·11 per cent. of pit-scrap was made.

The effect of record-breaking on the proportion of second-quality rails we have already considered.

8. He says that *during record-breaking the moulds are insufficiently cooled.* The effects of insufficient cooling should be, first, to cause the ingots to stick in the moulds, thus delaying operations hopelessly, and so preventing record-breaking, and causing cracks in the ingots, and thus leading to increasing the proportion of second-quality rails; and, second, to hasten the destruction of the moulds.

But we find that in October 1889, at the Union Works, the moulds lasted unusually long, viz., an average of 92·63 heats each. This agrees with common experience and common sense—that it is only by the closest attention to such details as the proper cooling of the moulds that great speed can be maintained.

9. He says that *during record-breaking the ingots are stripped too soon.* If the ingots are to be heated on end, which is thought the best practice, and which is done at the Union Works, they, cannot be stripped too soon, so far as quality is concerned. The only danger in very early stripping is that the ingots may bleed; but the low proportion of pit-scrap, 2·21 per cent., already referred to, shows that no serious amount of bleeding can have occurred.

10. *Any of the evils,* 5 *to* 9 *inclusive, would seriously impair the quality of the steel.* The statement that either careless scrapping, or irregular setting, or insufficiently cooling of moulds, or early stripping of ingots would seriously injure the steel, points to that "going with a rush" into print, which Mr. Potter deplores as applied to Bessemer practice.

11. *During record-breaking the ingots are either over- or under-*

heated; rolls are not changed often enough; neither are the saws, so that they cut roughly and inaccurately; rails are straightened so hot that they thereafter warp in cooling. Charges easy to make, hard to refute. Each of these evils would be likely to lead to rejection by the purchaser's inspectors, and should thus diminish the shipments of rails. For if the steel were not at the desired temperature on entering the rolls, neither would it be on leaving them and on sawing; hence its contraction after sawing would be either too great or too little, and the rails would not be true to length, and should be rejected. If the rolls were not changed often enough, the rails would not be true to section, and should be rejected; so, too, if the saws cut irregularly, the rails, not being true to length, should be rejected.

Turning now to the facts, we find that in the record-breaking month of May 1888, at the Union Works, the shipments of rails were 96 per cent. of the weight made, which tallies ill with the Bedlamite reign of terror which Mr. Potter so ruthlessly exposes.

12. It is hard to comment on Mr. Potter's remarks about insufficient hot-beds. Nobody applauds insufficient hot-beds, nor do they form a feature of American rapid practice. There is room in our country for all the hot-beds needed. Nor is it common American practice during record-breaking to cool rails with water. It has been done after the rails have become perfectly black, but never, so far as I know, injuriously. In stating that, at the mill he clearly refers to, it took three months to straighten and ship the excess of rails piled in the yard during a single record-breaking month, I have it on direct authority that Mr. Potter is wholly misinformed.

13. He says that *our machinery does suffer from over-driving incident to beating the record.* A bare assertion, wholly unsupported by evidence. To reconcile it with the detailed statements as to the actual endurance of our machinery given in the body of my paper, and with the almost record-breaking output kept up during the greater part of the seventeen successive months given in Table IV., few will find easy.

Looking at it now in a general way, it should be apparent to every one experienced in executive work that, where great speed is to be kept up for a month at a time, the very administrative difficulties which must arise demand as a fundamental condition that there shall be no mad rush; that every detail shall not only be carefully thought out before-hand, but carefully executed. "The utter recklessness," the "slovenly careless work," "the mad struggle" which exist, according to Mr. Potter, must necessarily defeat themselves. He who would run a rod at highest speed may indeed rush madly; he whose army spans a continent the swiftest, husbands his resources, looks well to diet and shoeing, while he must not waste time, neither dare he waste strength. What protracted struggle against time or man or beast was won by utter recklessness, mad rushes, carelessness and slovenliness?

While, like Mr. Potter and every other sane man, I would not commend record-breaking "for universal practice," I am confident that its occasional practice is desirable; for, in preparing for a record-breaking effort and in carrying it out, expedients are devised in the way of organisation and of detail of procedure; short cuts are established, which are used after the effort has ceased, and which may introduce great economies. Witness our low-silicon practice. A speed is reached which, indeed, cannot be long sustained then; but the experience gained permits a greater permanent speed than was possible before the spurt, and, when we return to normal speed, it is no longer that which was normal before. Little by little the organisation adapts itself to this new speed, till it is as easy as the old was. Then comes a new spurt, with another rise of the normal speed. After a number of these elevations of the normal, we find that it is far, far beyond the maximum speed of our early spurts. Thus the average output of the seventeen consecutive months in Table IV. is 78 per cent. greater (or, if we omit the three months in which extraordinary delays from strikes, orders from the directors, and for the annual stoppage for general repairs, 90 per cent. greater) than the 15,000 tons which Captain Jones looked forward to in 1881 as the probable limit which we might some day reach.

I am confident that these spurts have, on the whole, been productive of good, both to mill-owners and the public; that it is in no insignificant degree due to them, and to the talent which has directed them, that the cost of the Bessemer process has diminished so greatly; that in general—certainly in the cases which Mr. Potter singles out for attack—haste *has* been "tempered with reason and good judgment."

I am surprised that Mr. Potter thinks that either the intelligence or the character of the men who have broken our records would permit them to sacrifice the interests of which they are the trustees in the way he depicts, especially when the President behind has his finger ever on a button, which would blow the earth from beneath the manager's feet.

[TABLE IV.—WORK.

TABLE IV.—*Work done at the Union Bessemer Mill with Two 10-Ton Vessels.*

Month.	Output per Month, Tons of Ingots.	Turns.	Tons of Rails per Month.	Turns.	Average per Cent. Silicon.	Average Length of Blow, Minutes.	Average Blast Pressure, Lbs. per Square Inch.	Average Number of Heats per Hour.	Average Life of Bottoms, Heats.	Relative Number of Heats per Hour, 1·00 = the Lowest.	Relative Proportion of 2nd Quality Rails, 1 = the Average.	Relative Variation of Carbon, 1·00 = the Lowest.
1889.												
July	28,212·9	47	22,983·5	47	...	...	...	...	...	...	...	...
August	30,264·4	50	25,107·3	50	...	...	...	...	...	...	...	...
September	26,264·3	46	21,151·4	46	...	...	...	...	...	...	...	...
October	36,232·8	54	28,491·6	54	...	...	...	...	...	...	...	...
November	20,699·1	36	17,771·3	36	...	...	...	...	...	...	...	...
December	13,235·5	35	12,091·9	26	...	...	...	...	...	...	...	...
1890.												
January	32,546·0	50	26,555·6	50	0·887	9·98	25·28	5·07	23·75	1·29	1·07	1·66
February	28,454·5	44	23,053·5	44	0·876	9·39	25·10	4·93	24·34	1·25	0·97	1·55
March	27,494·7	47	22,756·0	47	0·967	9·60	24·40	4·42	23·35	1·12	1·28	1·22
April	28,825·4	48	23,151·8	48	0·952	9·19	25·60	4·57	22·51	1·16	1·19	1·22
May	21,389·8	39	17,469·4	39	0·999	9·23	26·90	4·04	20·70	1·03	1·60	1·88
June	25,016·3	46	20,298·5	46	1·128	9·84	26·52	4·24	19·64	1·07	1·04	1·55
July	135,708·0	...	...	...	1·103	9·80	26·60	4·20	19·00	1·06	1·03	1·33
August		...	...	...	1·086	10·00	27·50	4·20	17·73	1·06	0·60	1·44
September		...	...	...	1·067	9·69	27·60	4·56	22·00	1·15	0·65	1·22
October		...	...	...	1·035	10·02	27·34	4·64	21·10	1·18	0·87	1·11
November		...	...	...	0·966	10·11	26·12	3·94	19·50	1·00	0·84	1·00

Proportion of ingots, &c., from January 1, 1890, to December 1, 1890.

Ingots	87·43
Butt-ingots	0·66
Pit-scrap	2·11
Iron scrap	0·20
Loss	9·60
	100·00

ALUMINIUM-STEEL.

By R. A. HADFIELD, Sheffield.

I.—Introduction and Early History.

It seems a specially fitting opportunity to present a paper on Alloys of Iron and Aluminium at the New York Meeting of this Institute, owing to the fact that America has, more than any other country, originated and developed the manufacture of cheap Aluminium. The Cowles, Castner, and Hall systems have all originated in the ever-busy brain of our cousins across the water.

The problem of cheaply producing this valuable metal has been a difficult one, but to the writer it seems that, the more arduous the task, the greater the delight with which our American friend attempts to overcome the difficulties surrounding it, and the more *vim* he throws into the work. Another and equally striking proof of this is to be found in the recent appearance of the already well-known remarkable work, "Metallurgy of Steel," by Mr. H. M. Howe, of the Institute of Technology, Boston, Mass. It is to be hoped that this Institute will not be slow to recognise by some special mark its appreciation of this signally valuable and original work.

The writer has been led to describe the following experiments, believing that so far no full and exact report has yet been presented to this Institute as to the effect of Aluminium alloyed or combined with the metal Iron.

It has been a special object to make the material as far as possible a true alloy or combination of Aluminium and Iron, with as small quantities as possible of other disturbing ingredients, such as Silicon, Manganese, &c. In the material described in these experiments, the total amounts of other elements present (Sulphur and Phosphorus being disregarded as present in such small quantities) do not exceed about ·50 per cent. Such material may therefore be probably taken as fairly illustrative of the effect of the metal Aluminium upon Iron. Since completing his experiments, the writer understands that Mr. Riley has also made some tests, the other elements present in his case amounting to about 1·00 per cent. The samples now under examination may therefore be considered as more nearly approaching what may be termed for the sake of convenience Aluminium-Steel, especially as the disturbing element, Manganese, is unusually low.

It is not proposed to deal, except briefly, with the actual production of the interesting metal Aluminium. A metal the price of which has been reduced in little more than thirty years from 6s. per oz. to 6s. per lb. must have an interesting history. This metal without doubt must play a considerable part in the metallurgy of the future; and whilst there has been much exaggeration* about it,—and those who exaggerate its qualities and capabilities are its worst friends,—still, a metal whose specific gravity is only 2·6; a cubic foot of which weighs only 160 lbs., against Iron 440 lbs., or Silver—to which it has points of resemblance—650 lbs.; a tensile strength about 10 tons per square inch; is inoxidisable in a high degree; and has high electro-conductivity, must indeed have an assured and prominent future.

Whilst the metal itself has proved so difficult of extraction, it is to be found in its oxidised state very abundantly in Nature. Native metallic Aluminium has not been met with. Somewhat curious, as pointed out by Mr. Richards in his interesting book on the metal, is the fact that the oxide, Alumina, unlike Silica, which it resembles in many respects, has, notwithstanding its abundance, not been found in animals or plants.

It is not believed that the metal was in any way known to the ancients. Although the term Alum, the *Alumen* of the Romans, occurs in Pliny's and other ancient writings, yet it has not been satisfactorily proved that our Alum was the substance referred to. On the contrary, the learned Bechmann has asserted that the "Alum" of the Greeks and Romans was Sulphate of Iron, and that the invention of our Alum was much later in the twelfth century. It was certainly mentioned by Chaucer in 1356.

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* One scheme propounded and abundantly circularised was to have its outcome in the production of 400 tons per month of Aluminium and its alloys. The profit was to amount to the modest sum of £20,000 monthly! No wonder such a prospect was entitled "A New Era in Metallurgy."

A well-known technical journal published a statement that "Aluminium can be hardened until the diamond is its only rival!"

Speaking briefly of its early history, Margraff proved, in 1754, that the earth Alumina was a metallic oxide. Sir Humphry Davy, in 1807, unsuccessfully attempted to extract the metal by means of the electric current, and was followed by Oerstedt, the Dane, in 1827; but the great chemist Wohler, in 1827, and more completely in 1845, must be credited as being the true discoverer. Bunsen showed in 1854 how the metal could be obtained by electrolysis. St. Claire Deville, of France, as is well known, was the first to take up and perfect the early manufacture of the metal on a commercial scale.

Our own Dr. Percy, in 1855, was, through the outcome of some laboratory experiments, the first to develop the improved process of making the metal from the fluoride, and, still later, another member of this Institute, one of our past Presidents, Sir Lowthian Bell, devoted much time and attention to the problem.

Professor Williamson, in his address to the Chemical Section of the British Association, in 1863, referred to this, stating "One of the most interesting metals in metallurgy is the manufacture of Aluminium, now carried out chiefly for the sake of its alloy with Copper by the distinguished gentleman who holds the office of Mayor of Newcastle (now Sir Lowthian Bell). The mechanical properties of this so called Aluminium-Bronze give it great value, and it seems likely to find much favour owing to its appearance."

At the same meeting Sir Lowthian Bell read a paper "On the Manufacture of the Metal Aluminium," and mentioned that it had then (1863) been carried on some 3½ years at his Washington Works. His process consisted in the employment of bauxite, mixed with the ordinary soda-ash of commerce, and heated in a furnace, the remainder of the process being similar to that of M. St. Claire Deville.

Sir Lowthian Bell then stated that the increased activity in the manufacture of Aluminium was due to the value of the alloy of this metal with Copper, and that this "alloy, or Aluminium-Bronze, as it is termed, was the discovery of Dr. Percy;" and he considered it to be a true chemical compound. He specially pointed out the fact that the union of the two metals, Copper and Aluminium, was attended with such increase of temperature, that unless the crucible was of good refractory material it would become fused. He also pointed out—and it must be remembered this was nearly thirty years ago—that one of the best bronzes (in its forged state), that is, one of the strongest, most malleable, and ductile, was that containing 10 parts of Aluminium and 90 of Copper—a fact now offered as a recent discovery by some writers on the subject.

Dame Nature keeps most of her secrets very tenaciously locked up, and no doubt in many ways this is a good thing; but none of her problems have proved more difficult than that of finding out how to produce the metal Aluminium *cheaply*. Too great praise cannot be given for the amount of patient and laborious investigation by the many scientists and practical men who have worked at its solution, and who recognised that if methods could be perfected to this end, there would be a great future for the metal.

During the last ten years, Cowles, Netto, Castner, Grabau, Héroult, Minet, finally culminating in Hall's process, taken up by the Pittsburgh Reduction Company, have all worked successfully. That we are fairly on the road to the desired cheap production may be gathered from the fact that its commercial value has been reduced to 6s. per lb.; and the writer believes that he is correct in stating that by the Hall and other processes, and notwithstanding these later lower prices, the manufacture of Aluminium is now being profitably pursued.

Name.—A recent interesting paper to the American Institute of Mining Engineers by Mr. Oberlin Smith, entitled "Aluminium in Search of a Nickname," refers to the title which should be bestowed on the metal. Whilst hardly agreeing with him that we should come down to the short, but somewhat undignified term "Al," both that of "Alumin*ium*" (adopted in England), or "Alumin*um*" (as in America), are somewhat awkward. It seems to the writer that as "Aluminium" seems in several ways to resemble "Silic*on*," as will be seen from the experiments detailed in this paper, it might be well to name the metal "Alumin*on*." One now seldom hears the old term "Silic*ium*," besides which the affix "ium" belongs to metals with quite distinctive qualities, such as "Sodium," "Potassium," "Lithium," &c., and it would make our now cheaper but respectable friend fall more in line with the ordinary wording at present adopted. The above suggestion would also meet the objection raised by American friends, who rightly contend that if "Alumin*ium*" is adopted, the oxide should be termed "Alumin*ia*," which no one would defend. The title

'Aluminon" would, however, meet both cases, as well as prove more euphonic.

Processes of Manufacturing Aluminium.—As is well known, the properties of Aluminium are essentially modified by even very small proportions of impurities, both as regards resistance and changeableness; but all the users of the following systems claim to supply it in purity from 97 per cent. upwards.

The principal processes now commercially used in the manufacture of the metal are:—

The Castner process, carried on by the Aluminium Company at Oldbury, Birmingham, England. This is too well known from the excellent papers and descriptions given by Sir Henry Roscoe to need further reference here.

The Netto process, employed by the Alliance Aluminium Company, Newcastle-on-Tyne, which has been described by Professor Williams, of Firth College, Sheffield.

The Cowles electric system, differing from the others in the fact that it preferably produces alloys of Aluminium with other metals, and not the metal itself, is also well known.

The Grabau method, based upon the reduction by sodium of fluoride of Aluminium, produced from the action of sulphate of Alumina upon fluor-spar and cryolite. As the latter mineral is reproduced in large quantity during the process, in an artificial form, it is of a much higher degree of purity, and therefore it is claimed that a metal of exceptional purity can be obtained. The sodium used in the operation is obtained by electrolysing melted chloride of sodium in a crucible, one electrode being of carbon and the other an iron wire. As compared with the Deville process, this is said to utilise the sodium more perfectly, viz., from 83 per cent. to 90 per cent. of the reducing effect being realised, as compared with 76 per cent. by the former method.

The cheapness of the product by this method, according to M. Ichon, in the *Annales des Mines,* depends on the electrolytic process of manufacturing the sodium, which M. Grabau claims to be able to produce at from 7d. to 9d. per lb., or about one-tenth of the current rate. This inventor, in consequence, claims to produce Aluminium at the cost of about 5s. 10d. per lb., on an output of as little as 50 lbs. of metal (99 per cent. purity) per twenty-four hours. The cost of plant to accomplish this is stated as

£7300. The working expenses and the cost of materials are taken at £12 per day of twenty-four hours, to give the above-named output. As it is the most recent estimate of cost, it may be interesting to give this inventor's figures:—

Investment.

	Francs.
Buildings	57,000
Steam-engine, boiler, dynamo	35,000
Electric apparatus for making sodium	22,000
Sundry apparatus	25,000
Working capital	40,000
	Fcs. 179,000

Working Expenses.

	Francs.
Labour, per day	40,00
Chemists	40,00
Fluor-spar	12,00
Sulphuric acid	2,50
Sulphate of Alumina	60,00
Sea-salt	36,00
Various chemical products	16,00
Coal	50,00
Repairs and sinking fund	30,00
	Fcs. 286,50

Or about 14·30 francs per kilogram of Aluminium produced.

The Héroult * process, in use at Neuhausen, consists in decomposing melted Alumina by a powerful electric current between carbon electrodes. The oxygen is disengaged at the anode, burning off in carbonic oxide. The metal is produced in a carbon-lined cast-iron vessel. If it is desired to produce pure Aluminium, a quantity of liquid cryolite is poured into the vessel, and also Alumina. The negative electrode is a carbon rod, lowered into the bath. Aluminium Bronze and Iron are manufactured by this process in a similar manner, the only difference being that the melted Copper or Iron ore are poured into the bottom of the bath, and no cryolite is used.

M. Ichon, in the *Annales des Mines*, states that MM. Bernard

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* This process has been fully described by Mr. Dewey, in a paper to the American Institute of Mining Engineers, Washington, 1890. It is only fair to Messrs. Cowles to state that they consider this modification an infringement on the principles of their patents. To these gentlemen we certainly owe the rapid development, if not practically the introduction, of the electric arc furnace.

Frères of Creil, who exhibited at Paris last year, claim to be able to produce the metal at as low as 4s. per lb. (cost price), but the writer has not seen this substantiated.

Finally the latest system, viz., Hall's, assisted by Messrs. Hunt and Langley, carried on by the Pittsburgh Reduction Co., and in England by the Metal Reduction Syndicate, Manchester, has been fully brought before the public in a recent paper,* read before the American Institute of Mining Engineers (Washington, 1890), on "The Properties of Aluminium, with some Information relating to the Metal."

According to a recent American paper, this Company, having met with so much success in its preliminary work, proposes to erect large new factories, which, according to a recent Pittsburgh paper, are to possess 10,000 horse-power. The same source states that they already make over 400 lbs. of Aluminium per day (in 1887 the world's production did not probably exceed 10,000 lbs. per annum), and that they import at present, from Germany, ore, or rather clay, from which the metal is extracted. The same paper states that Aluminium made by this Company has been supplied in considerable quantities for ornamental work in the cabins of the latest ocean steamers, and that it has been adapted to the manufacture of table cutlery with success.

The English branch of this Company established at Manchester state that they believe that as the demand grows and the prices of the raw materials used, come down, the selling price of the metal can be reduced to even under 6s. per lb.

Aluminium Copper and Bronze.—Having mentioned the principal methods of producing the metal itself, reference may be made to the already large employment of Aluminium alloyed with Copper, known as Aluminium-Bronzes, for quite a countless number of purposes. It may be interesting here to state, as one of the first public notices, that in the *Morning Star* of May 21, 1862, considerable reference was made to the probability of Aluminium-Bronze coming into extensive use. The many good qualities of these alloys will no doubt make the use of Aluminium in this direction alone of very wide importance.

The following table gives the range of tensile strength and density of these forged Aluminium-Bronzes:—

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* This is the most complete and comprehensive paper yet published on the properties of the metal.

TABLE A.—*Tests of Aluminium-Bronzes.*

By Mr. JOHN H. J. DAGGER, in a paper read before the British Association, 1889.

	Tensile Strength in Tons per Square Inch.	Elongation.	Density.
		Per Cent.	
Aluminium-Bronze 11 per cent. Al.	40 to 45	8	7·23
,, ,, 10 ,, ,, .	33 ,, 40	14	7·69
,, ,, 7½ ,, ,, .	25 ,, 30	40	8·00
,, ,, 5–5½ ,, ,, .	15 ,, 20	40	8·37
,, ,, 2½ ,, ,, .	13 ,, 15	50	8·69
,, ,, 1¼ ,, ,, .	11 ,, 13	55	...

The brittleness of alloys above 11 per cent. prevents their use. Those containing 60 per cent. to 70 per cent. Aluminium are very brittle and beautifully crystalline; with 50 per cent. the alloy is quite soft, but under 30 per cent. the hardness returns. The 20 per cent. Bronze has a whitish-yellow tint, somewhat resembling bismuth, but is very brittle, and can be pulverised in a mortar.

One of the most valuable properties of the alloys given in the above table is the fact that they are forgeable, and can be worked at a red heat.

Table B. having been specially prepared by Professor Tetmayer, of the Polytechnic School, Zurich, for the Aluminium-Industrie Actien Gesellschaft, at Neuhausen, is given for the purpose of comparison with the foregoing.

TABLE B.

	Aluminium.	Tensile Strength in Tons per Square Inch.	Elongation.
	Per Cent.		Per Cent.
Aluminium-Bronze . . .	11·50	52	0·50
,, ,, . . .	11·00	44	1·00
,, ,, . . .	10·00	42	11·00
,, ,, . . .	9·50	40	19·00
,, ,, . . .	9·00	37	32·00
,, ,, . . .	8·50	33	52·50
,, ,, . . .	5·50	28	64·00
Aluminium-Brass . . .	4·00	45	6·50
,, ,, . . .	3·00	39	7·50
,, ,, . . .	2·50	34	20·00
,, ,, . . .	2·00	31	30·00
,, ,, . . .	1·50	29	39·00
,, ,, . . .	1·00	26	50·00

Professor Tetmayer has plotted his results, the curve obtained showing that with increasing Aluminium contents the tensile strength increases slowly at first, but then grows rapidly as the alloy is made richer in the lighter metal.

Alloys of Cast Iron and Aluminium.—As with other cast Iron, Aluminium-cast-iron, if it may be so termed, naturally comes under a different classification to that of the malleable compounds of Aluminium and Iron, and it is not intended to deal with it here. We are again indebted to Americans for information in this direction, especially to Mr. Keep, who has done so much to place the system of producing and mixing Irons for iron-foundry purposes on a more exact and scientific basis. He has already published a series of valuable investigations in a paper presented to this Institute last year on "Aluminium in Carburetted Iron," and in others read before the American Institute of Mining Engineers. He found that Aluminium has, in a considerable degree, a similar influence to that of Silicon upon cast Iron, a fact strikingly confirmed in some special experiments of the writer relative to the action of Aluminium upon combined Carbon in Spiegeleisen, and described later on. It is, however, only proposed to deal here with Aluminium in its use in the manufacture of steel, or steely compounds. There appears to be much misconception as to whether its employment is productive of good, and the writer confesses that he believes that whilst the price remains so high, and except in certain special cases, its application does not seem likely to become large. Aluminium appears to be of most service as an addition to baths of molten Iron or Steel *unduly* saturated with oxides, and this, in properly regulated Steel manufacture, should not often occur. Speaking generally, its *rôle* appears to be similar to that of Silicon, though acting more powerfully. It must, however, be remembered that these experiments have been made with practically pure Aluminium. If pure Silicon were also obtainable, its effect would probably be found to be almost the same. So long, therefore, as Ferro-Silicon, varying in Silicon from 8 to 20 per cent., can be obtained at from £3, 10s. to £10 per ton, as compared with Aluminium or Ferro-Aluminium of like percentages costing £112 to £250 per ton, it will be seen that the probable field of usefulness for the latter must be much circumscribed, cost being so much an element now-a-days. This fact, however, need in no way interfere with an examination as to its influence upon the metal Iron. The writer will, as far as practicable, endeavour to deal with the subject in a similar manner to that followed in his experiments with alloys of Iron and Manganese, Iron and Silicon, and other alloys.

CAST ALUMINIUM-STEEL.

Melting.—The material obtained for these experiments was produced by melting in crucibles, in the ordinary manner, good wrought bar iron, and adding the Aluminium (about 98 per cent. Al.), manufactured by the Pittsburgh Reduction Co.'s system, shortly before teeming. The writer takes this opportunity of expressing his thanks to Captain Hunt, one of the Directors of the Pittsburgh Co., for a liberal supply of the metal for experimental purposes, and as the Company in question was probably the first to sell the metal under 10s. per lb., it is to be hoped that the Hall system will meet with increasing success.

Although a difficult one, the object was to obtain an alloy or compound consisting as nearly as possible of Aluminium and Iron alone. In the material made, it will be found that the other elements present do not amount to more than ·50 per cent., so that this intent may fairly claim to have been accomplished. The ingots, 2½ inch square, were reduced by forging in the ordinary manner to bars of 1⅛ inch diameter.

The consideration of the qualities of these alloys is divided into two heads: first, the material in the *cast*, second, the material in the *forged* state.

Cast State.—Nothing special was noted during the melting operations, but in all cases, upon adding the Aluminium, "coruscation" was observed. This evolution of heat and light has also been observed when alloying Aluminium with Copper. Does not this tend to indicate that Aluminium added to Iron produces true compounds and not merely alloys, as it is well known in laboratory operations that the evolution of heat during the mixture of two substances is often a sign of chemical union? The curious properties of Manganese-Steel seem especially to prove that such a material is a true compound, and no doubt Aluminium-Steel may be classed under the same head.

Fluidity.—It is doubtful whether Aluminium increases the fluidity of properly made Steel, but if it does, the apparent increase or evolution of heat just referred to seems to the writer far more likely to account for any increase of fluidity that may occur, rather than to the so-called lowering of the melting-point. This is discussed more fully a little farther on.

As the Aluminium increases to large amounts, over about 0·50 per cent., the metal becomes quite thick, "creamy," and sets quickly. No doubt this is partly caused by a considerable portion of the Aluminium being oxidised to Alumina, and becoming entangled as slag, in the same way as occurs when Silicon is oxidised to Silica. Unless suitable flux is present, this excess of oxide cannot be carried off, the molten metal becomes less fluid, and causes the "thickness" noticed. There is a resemblance in this respect to the action of high percentages of Silicon added to Iron. When exceeding about 0·75 per cent. Al., the molten material so rapidly "creams over" on the surface, that the production of sand-moulded articles is only effected with difficulty; in fact, it was only by using considerable care that the cast test bars were obtained.* It must not be overlooked that the writer is here referring to comparatively high percentages. So far as his own experiments have gone, Aluminium, as regards lower percentages, also acts in a similar manner to Silicon under the same circumstances.

So much has been said as to Aluminium lowering the melting-point of Iron, that the writer wonders how and why this statement was originated, as it certainly seems to have no foundation in fact. This is confirmed by M. Osmond, who by means of the Le Chatelier pyrometer kindly made for the writer a special determination as to the melting-point of an alloy containing 5 per cent. Al. and about 94½ per cent. Fe. The sample in question did not show the slightest signs of fusion until a temperature of 1475° C. was reached. As mild Steel, by the same pyrometer, was shown to fuse at about 1500° C., there could have been little or no lowering of the fusion-point; and if this is the case with an alloy containing 5 per cent., still less can it be so with one containing only 0·10 per cent., which is the quantity usually described as being present when the so-called lowering-point is supposed to occur. It is especially satisfactory to have the testimony, not only of M. Osmond, but that of Mr. H. M. Howe,* who both agree with the writer on this point.

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* Mr. Keep, even with Cast Iron, found a decided decrease in fluidity by the addition of Aluminium.

As this question is so important, it may be well to give a translation of M. Osmond's exact words:—"I carried the heating of your sample up to 1465° C. At this temperature slight oscillations of the spot of light on the scale appeared to denote the approach of fusion and, in fact, after the cooling down I noticed slight indications of fusion on that portion of the sample which had been in contact with the tube. We can, therefore, suppose the actual fusion-point would be about 1475° C. As ordinary soft steel by the same pyrometer [Le Chatelier] is shown to melt at about 1500° C., you can see that your 5 per cent. Aluminium sample had its fusion-point only lowered about 25°, or scarcely anything. It is, therefore, absolutely untrue that 0·10 per cent. of Aluminium can lower the fusion-point many hundreds of degrees, as has been so commonly stated." †

In the writer's opinion, if any increase of heat or fluidity takes place by the addition of small amounts of Aluminium, it may be due to either of the following causes, or to both combined. First, there may be evolution of heat owing to oxidation of the Aluminium, as the calorific value of this metal is very high—in fact, higher than Silicon. According to Berthollet, the conversion of Aluminium to Al_2O_3 equals 7900 cals.; Silicon, to SiO_2, is stated as 7800.

This oxidation is probable, as in the writer's experiments the addition of Aluminium to Iron was always accompanied by more or less, and often considerable, loss of the former metal. This is also proved by the fact of its appearing in the oxidised state in a white powder upon the side of the ingot mould, as well as in the slag, as well as from the fact that when small amounts are added they are rarely found in the product when being analysed. In the 5 per cent. specimens previously referred to, the writer found that no less than 2 per cent. was wasted. Against the supposition that increase of heat is obtained by oxidation must, however, be placed the fact that when the Aluminium exceeds say about 0·75 per cent., the less fluid is the product and the more metal is wasted; but at the same time the explanation first offered might still hold good as regards the lower percentages, say under 0·50 per cent.

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* Mr. Howe publicly questioned the inaccurate statements then circulated on this point more than three years ago in a leading technical journal.

† Messrs. Hunt, Langley, and Hall say in their paper when referring to Aluminium-Bronze: "The melting-point of 10 per cent. Aluminium-Bronze is 1700° F., a little *higher* than that of ordinary bronze." There is no lowering of melting-point here, although 10 per cent. of Aluminium was present.

Secondly—and more probably the correct explanation—as proved in a very clear and able manner by Mr. Galbraith, in his interesting paper to the Iron and Steel Institute in May last, the fluidity of molten Iron and Steel depends not only upon the amount of heat imparted by external means, or by oxidation, but often upon the quantity of intermingled slag, or oxide of Iron. He found that in certain cases, in excessively over-oxidised Steel, although the heat of the furnace was *more* than usual, the product was still lacking in fluidity. It would be interesting to have the point followed up and thoroughly tested by means of the Le Chatelier pyrometer. As supporting this, it may be observed that the well-known German metallurgist, Ledebur, believes the *rôle* of Aluminium "to be no other than that of destroying the dissolved oxide of Iron present."

That such over-oxidised metal possesses different properties as compared with ordinary Steel or Iron is very clear, for the writer has had brought under his notice certain cases of over-oxidised Iron which continue to rise, give off gases, and prove unsound in the ingots, notwithstanding the addition of even considerable quantities of Aluminium. They are, of course, exceptional, and seem to the writer to be explained by the facts pointed out by Mr. Galbraith.

The loss of the metal in melting is variable, but in nearly all cases it amounts to a considerable proportion of the percentage added. The writer has seen it stated that there is no loss, although at the same time it has been mentioned that a considerable scum of Alumina was noticed. The two facts are inconsistent, as if the latter was present it would appear that of necessity more or less of the metal added must have been oxidised, and consequently not present in the final product.

Soundness.—Does the addition of Aluminium produce sounder material than Silicon, Manganese, or Silicon combined with Manganese? Whilst it has been found to act powerfully in this respect, like these metals, still it does not follow, as much of the literature on the subject would have us believe, that blow-holes are quite done away with, and that the steel-founder may come down to his works in the morning without paying the usual visit to the scrap heap. The art of the steel-founder is not merely the production of sound Steel, which, by increased knowledge, and choice of alloys for producing soundness, is, whilst still complicated, not so difficult as formerly, but consists, amongst other things, in the careful attention to the preparation of the moulds into which the molten Steel is poured. There is no rapid or royal road to the production of sound Steel castings; this is only attained by long experience combined with specialised knowledge. Mere attention to the chemical composition of the Steel will not produce the desired results; and the writer hopes that these words will be remembered by those who are anxious to embark in the production of Steel castings, and who consider, from reading certain literature, that it is perhaps only necessary "to buy so much Aluminium, add 0·10 per cent., lower the melting-point, and the result will be perfection."

One cannot be surprised that strong hopes are raised when, shall we say, ill-advised trade pamphlets make such statements as that by the addition of Aluminium to Iron—mark the number, ye Muses—*nine* distinct and important qualities are at once conferred. No wonder Ferrum has hitherto had to be classed amongst the baser metals, but is now to be rehabilitated by the nine-mused metal Aluminium.

The writer has seen, sold at shillings per pound, specimens of so-called Ferro-Aluminium, which, upon analysis, gave—Aluminium "Nil" per cent., Sulphur 0·24 per cent., Phosphorus 0·30 per cent.!

Not a little amusing, too, was the ingenious firm who, to meet ideas all round, offered a compound described as "Aluminium-Ferro-Silicon," which, according to the statements of their circular, should not only banish honeycombs from the realm of the steel-founder, but should, at the same time, "*de-phosphorise* and cleanse the metal of any excess of carbon!" Such an alloy, to quote from the circular, could well claim "to be of value in almost all ordinary Steel practice." Is there any wonder that steel-makers have become sceptical and suspicious as to new processes?

As high as 0·75 per cent. Aluminium, or even more, may be admitted without much interference with the ductility or toughness of the cast specimens, as will be seen from Table III. These experiments prove that more Aluminium may be present in the cast material than Silicon in cast Silicon-Steel before brittleness sets in. After reaching the region of brittleness, and by adding still higher percentages of Aluminium, there is no return of strength—on the contrary; so that this material in no way resembles the curious property noted in this respect with regard to Manganese-Steel.

Aluminium seems specially powerful in absorbing gases, and in Mr. Richards' book on the metal he states that M. Dumas found, on heating it in a vacuum, that towards a red heat considerable quantities of gases were given off, their composition being 88 c.c. H., and 1·50 c.c. CO^2.

In a pamphlet issued by the Alliance Aluminium Co. they state on this point that—

"As regards the affinity of Aluminium for Oxygen, it ranks next to the alkaline and ferro-alkaline metals—that is, its power of affinity for Oxygen is much greater than that of the metals proper, such as Manganese for example. Supposing the chemical equivalent of Oxygen to be represented, it is found that there is

Silicon	278
Manganese	345
Aluminium	171

"Comparing the absorption power of these three bodies, it will be found that

171 parts of Aluminium absorb 150 parts in weight of Oxygen.
171 „ Silicon „ 123 „ „ „
171 „ Manganese „ 49 „ „ „

"Relatively the absorption powers would be, therefore,

Aluminium	5·00
Silicon	4·10
Manganese	1·66"

It is not, however, clear how the above figures are arrived at, and they certainly seem inaccurate as regards Silicon.

Silicon (28 At. wt.) converted to Silica absorbs 32 of Oxygen, or the weight fixed by the Alliance Co., that is, 171 grms., absorb 195·35 grms. of Oxygen. This would quite alter the absorption table as given by them, which would read as follows, Silicon being now at the head:—

171 parts of Silicon absorb 195 parts of Oxygen.
171 „ Aluminium „ 150 „ „
171 „ Manganese „ 49 „ „

The relative powers would then be

Silicon	6·60	not	4·10
Aluminium	5·00	(the same)	5·00
Manganese	1·66	„	1.66

Bending Tests.—Table III. gives the bending tests, from which it will be seen that the annealed samples up to ·85 per cent. bent double cold; those unannealed were not so good. The gradual increase of Aluminium is very clearly shown to reduce the toughness both of the unannealed and the annealed specimens. They were sound, with the exception of samples E. and F., but not more so than cast Silicon-Steel of corresponding percentages.

Hardness.—As might be expected from the soft nature of the metal Aluminium, its addition to Iron does not add materially to the hardness, again in this respect resembling the effect of Silicon. Seven to eight per cent. of cast Aluminium-Steel may be readily drilled and filed. This point is dealt with more fully under "Hardness" in treating of the forged material.

Neither does its addition, unlike Manganese, interfere with the magnetic susceptibility of the Iron present. Experiments are in hand to determine what is the actual effect in this direction, and also as regards conductivity.

Appearance of Fracture.—Aluminium in the cast specimens opens the grain, *i.e.*, increases the size and coarseness of the crystals, and as the higher percentages are reached it is somewhat difficult to distinguish the fractures from those of the cast Silicon-Steel described in the writer's paper at last year's Paris Meeting of this Institute. The crystals in the 5 per cent. and upwards specimens become very large, and cleave somewhat after the nature of Spiegeleisen. This accounts for the increasing brittleness of the cast material, and neither the fracture nor the brittleness accompanying it in such samples can be changed by annealing. A curious fact was noticed, viz., that the freshly-broken fractures had a very pronounced odour of sulphuretted hydrogen, although the Sulphur present did not exceed more than 0·06 per cent. This remained for several days. Figures 4 and 5 give the appearance of the 5 per cent. Aluminium and Silicon samples in their cast state.

M. Osmond examined microscopically the fracture of a 5 per cent. specimen (previously heated to 1465° C.) of cast Aluminium-Steel (see fig. 1), and says, "It is a mosaic of polyhedrons of striking regularity, the interior of the polyhedrons being of remarkable homogeneity. What I found most interesting was a comparison of the difference between it and the structure of extra soft steel previously heated to a similar temperature. In the Aluminium-Steel the polygons are nearly regular hexagons or pentagons. The soft Steel sample (see fig. 2), on the contrary, shows itself to be composed of elements which arrange themselves parallel to each other and in clusters of long narrow section."

FORGED ALUMINIUM-STEEL.

Malleability.—As high as 5·60 per cent. Aluminium may be present before malleability ceases. This is about the same limit as in the Silicon-Steel described by the writer.

It may be pointed out, as regards the specimens under discussion, that they are very low in Manganese. Notwithstanding this, the malleability is satisfactory.

Mechanical Properties, &c.—As regards bending qualities, Table III. shows the results. Up to 2·24 per cent. Aluminium, the annealed samples bent double cold, but upon reaching 5 per cent. a great diminution of strength takes place, and annealing practically produces no effect.

In the testing-machine (Table I.), it will be seen that the elongations and reductions in area, although in some cases irregular, are high, the annealed samples showing, as might be expected, the better results. The samples were all tested on short lengths, 2 inches (Whitworth standard pattern ·7979 inch diameter, ·50 inch area), and the elongations are very good in those up to about 1½ per cent. of Aluminium; afterwards a gradual diminution occurs. This is brought out graphically in Diagram 1, Table II., and Diagram 2 may also be of interest as showing the effect of similar percentages of Silicon and Aluminium. Comparing the sample of Aluminium-Steel containing 1·6 per cent. Aluminium and ·12 per cent. Carbon, with Silicon-Steel of 1·60 per cent. Silicon and ·19 per cent. Carbon, the former has an advantage in elongation of one per cent. A characteristic of the Aluminium-Steel is that the reduction in area is greater; in this respect it seems to resemble Chrome-Steel.* There is, however, considerable difference in the tensile strength of the two alloys, the Aluminium-Steel being several tons less. The same remark applies to the permanent set point, which, in the annealed Aluminium-Steels, is fairly low. Numerous comparisons might be drawn between the two Steels, especially as the test bars in both series of experiments were exactly the same in length and section, and were treated in all respects similarly. Reference to the diagrams and tables in each case will be found of interest. One difference clearly brought out is that the tensile strength of Iron is not increased so much by an addition of Aluminium as that of Silicon.

In two exceptional samples the writer was able to get the Carbon down to as low a point as ·10 per cent. with Aluminium, ·25 per cent. and ·96 per cent. respectively (these not forming a part of the series, are not included in Table I.). The elastic limits of the two annealed specimens were respectively 13 and 11 tons, with breaking loads 23 and 22·5 tons (per square inch of original area), very clearly showing the slight influence of Aluminium both upon the elastic limit and the breaking load.

It has been stated that very small percentages of Aluminium considerably raise the limit of elasticity. It will be seen from the table of tests, and specially from the two almost carbonless samples, just quoted, that this increase is slight, if any, as compared with ordinary Steel, and that Aluminium does not raise the elastic limit so much as Silicon. Seeing that Aluminium is an exceptionally soft and malleable metal, possessing a tensile strength of 8 to 10 tons, it is hardly to be expected that this should have been otherwise, and it is a pity that such incorrect statements as that mentioned are started, without foundation in fact. The elastic limit of samples should always be determined on annealed specimens as by cold forging or rolling, the elastic limit of even mild Steel can be readily raised several tons per square inch; and it would hardly be correct to call this the normal permanent set of the sample under examination. Aluminium and Silicon, therefore, stiffen Iron but little, whilst Carbon, Chromium, Tungsten, Manganese, and Nickel clearly increase rigidity; and this, from their nature and hardness, might be expected.

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* Messrs. Hunt, Langley, and Hall, in the paper before referred to, speaking of the metal Aluminium, say, "The flow of Aluminium under tensile tests is very *local*."

Compression Tests.—Samples A. and I. (·15 and 5·60 per cent. Al) were each subjected to a compression stress of 100 tons per square inch. Table IV. gives the full details. It will be noticed that whilst the specimen containing ·15 per cent. Al. shortened 51 per cent. in length under the above-named stress, that containing 5·60 per cent. Al. shortened 36 per cent. Thus even the soft metal Aluminium has to some, though a very slight, extent stiffened the material.

As a comparison may be mentioned samples B. and G. (Table III. of last year's paper) of Silicon-Steel (·79 per cent. and 5·20 Si.), which shortened under the same stress 50 per cent. and 32 per cent. respectively.

Hardness.—As might be expected from the soft nature of the metal Aluminium, its addition to Iron does not confer appreciable hardness when in either the forged or cast state. In this respect also it resembles Silicon-Steel. The forged material, containing 5 per cent., is very soft, easily drilled or filed.

The action of Aluminium may therefore be classed along with that of Silicon, Sulphur, Phosphorus, Arsenic, and Copper, as giving no increase of hardness to Iron, in contradistinction to Carbon, Manganese, Chromium, Tungsten, and Nickel. Water-quenching upon either forged or cast Aluminium-Steel (in which Carbon is practically absent) seems to produce no effect (Table V.), the samples when dipped at even a welding heat being almost unchanged.*

Here again we have another addition to the list of elements which, alloyed with Iron, do not produce "water-quenched hardness," if the term may be allowed. In fact, notwithstanding that Manganese, Chromium, Tungsten, and Nickel do impart a certain and considerable kind of hardness to Iron, either in the cast or forged state, Carbon retains its position as being the only element which confers upon Iron the property of becoming hard by water-quenching. In Steel made with the hard metals just mentioned, if the Carbon present be low, no matter at what heat they are water-quenched, the characteristic hardness of Carbon-Steel, such as scratching glass, or forming the edge of a cutting tool, is wanting.

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* It has been stated that the influence of Aluminium on high carbon, or tool Steel, is to destroy its hardening action. This is quite incorrect. The writer has prepared Steel containing 1½ per cent. Aluminium, and 1 per cent. of Carbon, which hardens sufficiently to scratch glass. It is a pity that such inaccurate statements are circulated.

Fracture.—Aluminium causes the tough percentages, both in the cast and the forged material, to break with dark fibrous fracture, similar to wrought Iron of good quality, only much darker in colour. This appearance in some of the specimens is very curious, as small patches of bright fine crystals are to be seen surrounded by a remainder of black and dark fibrous material.

In several of the tested tensile specimens, a rough and ribbed surface is noticed, proving looseness of texture.

Weldability.—Samples B (·61 per cent. Al.), D (·72 per cent. Al.), and G (2·20 per cent. Al.) were tested for welding, but unsuccessfully. It would be interesting to try electric welding.

The writer has always found that these special Steels or alloys, such as Silicon, Manganese, or Chromium Steel, have slight, if any, welding properties.

Application.—Speaking generally of the application of Aluminium to the manufacture of Iron and Steel, the usual amount stated to be requisite for producing good results is about ·10 per cent.; but in many cases, as already pointed out, this would be too little. Supposing, however, that an average percentage of ·10 per cent. or ·15 per cent. was necessary, and assuming the Aluminium to be sold at 8s. per lb., the expense of such addition would mean an extra cost of 18s. and 27s. per ton respectively; whereas if as much as even ·50 per cent. of Silicon is required to do the same work, it does not cost more than 4s. 6d. per ton. On a large output of Steel castings this means a serious difference, and in the above nothing is credited to the latter method by the gain of adding so much ferro-alloy, which afterwards counts as Steel.

In making these statements, the writer in no way wishes to disparage the efforts of those who have devoted so much time and attention to the production of Aluminium. Let it be rather an inducement to produce the metal more cheaply. If Aluminium can eventually be brought to compete in price with existing alloys, there is a probability of something being done in introducing its use on a larger scale. Aluminium may find a use for certain special purposes, such as in higher Carbon-Steel, where

Silicon does not seem to act so powerfully in producing soundness as in the case of milder Steel with Carbon ·50 per cent. and under.

Therefore, whilst for some special purposes Aluminium may be employed in the manufacture of Iron, at any rate with our present knowledge of its properties, this use cannot be large, especially when taking into consideration the fact of its comparatively high price. Its special advantage seems to the writer to be that it combines in itself the advantages of both Silicon and Manganese; but so long as alloys containing these metals are so cheap, and Aluminium so dear, its extensive use seems hardly probable.

Points of Resemblance between Aluminium and Silicon Steel.—Whilst referring to the points of similarity between the mechanical properties of Aluminium and Silicon Steel, there may also be mentioned an interesting communication sent some time ago to the writer by M. Osmond. He says:—"I believe you were quite correct in stating in your paper on Silicon and Iron alloys that the action of these two metals was very similar. All that I know on this subject goes to confirm this. In 1883 I made some Aluminium-Steel, and found its tensile strength and elongation were modified almost exactly as by the same proportions of Silicon. Second, Aluminium, like Silicon, causes a precipitation of graphite in cast Iron. Third,* The coöling curve of your Aluminium alloy is nearly the same as that of your 4·50 per cent. Silicon alloy. Fourth, Aluminium and Silicon have almost the same atomic volume. I will only add that I quite agree with Mr. A. H. Allen of Sheffield that ordinary Steel, made upon an acid-lined furnace, often contains a little Aluminium; at least I found it to be so with Creusot Steel, and by analytical methods which I believe to be accurate. I detected as high as ·10 per cent. in one sample, yet nobody found that the melting-point was lowered. The detection of small quantities of Aluminium is difficult, and requires great care, as reactions are likely to occur upon the glass utensils of the laboratory."

Owing to the similarity in behaviour of Aluminium and Silicon Steel in the testing machine, Table II. and Diagram 2 have been prepared for comparison. The full details of the Silicon-Steel samples will be found in Table II. of the writer's paper to this Institute last year.

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* M. Osmond has kindly furnished a tracing of the curve, see fig. 1.

It will be found from these that the samples selected, which fairly correspond as to their contents of Aluminium and Silicon, show the following results:—

The limit of elasticity does not at first differ materially, but in the higher percentages the Silicon-Steel gives the higher results. The same remark applies to the tensile strength.

As regards elongation, contraction of area, and bending tests, the differences are very slight. In fact, as a whole, it may be said that the two metals Aluminium and Silicon produce almost corresponding effects as regards mechanical properties when mixed or alloyed with the metal Iron. These facts are well illustrated by Diagram 2.

The further points of similarity may be summed up as follows: —Producing soundness; increasing the coarseness and size of the iron crystals; annealing, in the higher percentages of both Steels, produces very little change in the molecular structure; reducing fluidity in the higher percentages; neither metal appreciably hardens the Iron to which it has been added, no matter whether such alloy be in the cast or in the forged state; water-quenching produces no appreciable difference; the alloys produced by both metals cease to be malleable with about corresponding percentages; neither alloys weld satisfactorily.

The principal differences are that Aluminium-Steel, in its *cast* state, will carry a somewhat larger percentage of its metal before becoming brittle as compared with Silicon-Steel in its cast state, but after forging this appears to be removed. Larger amounts of Silicon seem to be required to produce the same soundness; but, as before pointed out, if it were possible to add pure Silicon,* it is probable that this difference would not be found to exist. The highest Ferro-Silicon yet made does not contain more than 20 per cent. of Silicon. Finally, Silicon-Steel appears to be more red-short.

Effect of Aluminium upon Manganese-Steel and Spiegeleisen.—Believing that Aluminium, like Silicon, would cause a precipitation of graphite, the writer added between three and four per cent. to ordinary Spiegel (12 and 25 per cent. Manganese). The result in both cases was a complete change from the well-known Spiegel fracture to that of ordinary close No. 3 grey pig Iron. Although there has been this great attraction in the form of the Carbon, no change in the non-magnetic properties of the Iron was apparent. This experiment therefore clearly proves that the neutralisation of the special magnetic qualities, ordinarily possessed by Iron, is in Manganese compounds quite independent of the particular state or form in which the Carbon present exists. The difference between the molecular structure of grey and white Iron, and, in the cases under consideration, between grey and white Spiegel, makes this fact somewhat striking.

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* If Messrs. Cowles would, with their electric furnace, supply us with say 50, 70, or 90 per cent. Ferro-Silicon, there would probably be a considerable use for such alloys. Ledebur considers that pure Silicon would act more powerfully.

The following table gives the analyses of the samples referred to, as well as of a sample of the same Spiegel to which Silicon has been added, with even more powerful results—the conversion of the greater part of the combined to graphitic carbon:—

	C.	Gr.	Si.	S.	P.	Mn.	Al.	Remarks.
Spiegel—								
12 per cent. before addition of Al.	4·80	none	...	...	...	13·65	...	There was considerable loss of Aluminium. Non-magnetic susceptibility unaltered. Fracture changed from usual pronounced "Spiegel" appearance to that of No. 3 Iron.
12 per cent. after addition of Al.	·93	3·45	1·30	·01	·05	11·75	3·19	
25 per cent. before addition of Al.	4·10	...	...	...	...	25·20	...	Ditto, except that the change was not quite so decided.
25 per cent. after addition of Al.	2·30	1·88	2·16	·02	·10	22·16	1·24	
12 per cent. before addition of Sil.	4·10	...	...	...	...	11·00	...	Fracture changed to No. 3 Iron. No change in non-magnetic susceptibility.
12 per cent. after addition of Sil.	·43	3·40	3·73	·01	·05	9·50	...	

In conclusion, the writer regrets that the paper is not so complete as he would like, but owing to press of ordinary work there has not been time to complete further experiments in hand, which might possibly have thrown further light upon this interesting subject.

TABLE II.—LITERATURE RELATING TO THE METAL ALUMINIUM.

Year.	Date.	Nature of Notice.	Where Given.	Author.	Titles.
1863.	May.	Press Notice.	*Morning Star.*	......	Aluminium Bronze.
1863.	...	Paper.	British Association	Sir Lowthian Bell.	On the Manufacture of Aluminium.
1888.	August.	Do.	American Association for the Advancement of Science.	Mr. W. J. Keep.	Influence of Aluminium on Cast Iron.
1889.	...	Do.	American Institute of Mining Engineers.	Do.	Aluminium in Cast Iron.
1890.	May.	Do.	Iron and Steel Institute.	Do.	Aluminium in Carburetted Cast Iron.
1890.	Feb.	Do.	Amer. Inst. of Min. Engrs., Washington.	Do.	Aluminium in Wrought Iron and Steel Castings.
1890.	Feb.	Do.	Do.	Do.	Aluminium and other Metals Compared.
1889.	April	Do.	Inst. of the North of England Min. Engrs.	Mr. H. Boby.	Aluminium.
1889.	Sept.	Do.	British Association.	Mr. J. H. Dagger.	The Uses of Aluminium.
1889.	...	Do.	Royal Institute of Great Britain.	Sir Henry Roscoe.	Aluminium.
1890.	Feb.	Do.	Amer. Inst. of Min. Engrs., Washington.	Messrs. Hunt, Langley, and Hall.	The Properties of Aluminium.
1890.	,,	Do.	Do. do.	Mr. E. H. Cowles.	Physical Properties of some of the Alloys of Manganese, Copper, and Aluminium.
1890.	,,	Do.	Do. do.	Mr. W. P. Black.	Note on the Use of Aluminium in the Construction of Instruments of Precision.
1890.	,,	Do.	Do. do.	Mr. E. H. Cowles.	Aluminium Bronze and Brass as Suitable Materials for Propellers.
1890.	,,	Do.	Do. do.	Mr. Oberlin Smith.	Aluminium in the Drawing Press.
1890.	,,	Do.	Do. do.	Mr. F. P. Dewey.	The Héroult Process of Smelting Aluminium Alloys.
1886.	Oct. 16.	Press Notice.	*American Machinist.*	Mr. T. A. West.	Production of Aluminium Bronze.
1886.	Nov. 12.	Do.	*Industries.*	......	Preparation of Aluminium by the Electric Furnace.
1887.	Aug. 30.	Do.	*Engineering and Mining Journal.*	......	Aluminium Alloys for Mine and Mill Machinery.
1888.	Aug. 30.	Do.	*Iron Age.*	......	Influence of Aluminium on Cast Iron.
1888.	Aug. 31.	Do.	*Engineering.*	......	Aluminium in Cast Iron.
1888.	Nov.	Do.	*Industries.*	......	Héroult Aluminium Process.
1889.	Dec. 12.	Do.	*Iron Age.*	Mr. Romaine Cole.	Aluminium.
1890.	Jan. 16.	Do.	*Do.*	Do.	Aluminium Copper.
1890.	May 2.	Do.	*Industries.*	......	Aluminium and its Uses.
1890.	Aug. 16.	Do.	*American Manufacturer.*	Mr. T. A. Wright, Pittsburgh.	Aluminium in the Manufacture of Russia Sheet Iron.
1890.	May.	Do.	*Le Genie Civil*, vol. xvi.	M. C. Talansier.	Héroult's Process for Manufacturing Aluminium.
1889.	...	Do.	*Annales des Mines*, vol. xvi.	......	Grabau's Method of Making Aluminium.
1890.	...	...	*Proc. of Inst. of Civil Engrs.*, vol. ci.	Mr. Jehon.	Do. do.
		Pamphlet.	......	The Alliance Aluminium Coy., Lim.	Aluminium: its Uses and Alloys.
		Do.	......	Do.	Aluminium and its Alloys.
		Do.	......	The Cowles Syndicate Coy., Lim.	Aluminium Alloys.
1887.	...	Book.	......	Mr. J. W. Richards.	Aluminium: its History, &c.

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TABLE III.—*Comparison Table of Forged Silicon and Aluminium Steel, both Materials having been Annealed.*

	Per Cent.			Limit of Elasticity in Tons per Square Inch.	Breaking Load in Tons per Square Inch.	Extension per Cent. on 2".	Reduction of Area per Cent.	Bending Test of Annealed Forged Bars.	Remarks.
	C.	Si.	Al.						
Si. Steel, A. .	·14	·24	...	15·17	25·0	37·55	60·74	Bent double cold.	The tests of the Silicon Steel are fully described in Table I. of the writer's paper, "Alloys of Iron and Silicon," read at the Paris Meeting of the Iron and Steel Institute in 1889.
Al. Steel, A. .	·15	...	·38	20·0	26·0	40·35	60·74	Bent double cold.	
Si. Steel, B. .	·18	·73	...	19·0	29·50	34·02	52·66	Bent double cold.	
Al. Steel, C. .	·18	...	·66	18·0	27·0	33·0	52·14	Bent double cold.	
Si. Steel, C. .	·19	1·60	...	25·0	33·0	35·0	54·52	Bent double cold.	
Al. Steel, F. .	·21	...	1·60	13·0	26·0	36·35	67·0	Bent double cold.	
Si. Steel, D. .	·20	2·18	...	25·50	34·0	36·50	59·96	Bent double cold.	
Al. Steel, H. .	·24	...	2·24	18·50	28·50	33·0	48·62	Bent double cold.	
Si. Steel, H. .	·26	5·53	...	29·00	39·00	0·70	2·00	Would not bend.	Test bar in both cases broke in the threads during test.
Al. Steel, I. .	·22	...	5·60	27·00	36·00	6·45	6·16	16° broken.	

Note.—These comparisons will be found plotted on Diagram 2.

TABLE IV.—*Bending Tests of Cast and Forged Aluminium-Steel.*

Series and Mark Referred to in Paper.	Al. per Cent.	CAST.		FORGED.		Remarks.
		Size of Bar, 6"×1"×¾"		Size of Bar, 4"×1⅛"×⅜"		
		Unannealed.	Annealed.	Unannealed.	Annealed.	
1167.	·15	79° broken.	Bent double.	Bent double.	Bent double.	
1167 A.	·38	Bent double.	Bent double.	Bent double.	Bent double.	
1167 B.	·61	174° unbroken.	Bent double.	Bent double.	Bent double.	
1167 C.	·66	88° broken.	Bent double.	Bent double.	Bent double.	
1167 D.	·72	59° broken.	Bent double.	Bent double.	Bent double.	
1167 E.	1·16	31° broken.	54° broken.	Bent double.	Bent double.	
1167 F.	1·60	28° broken.	133° broken.	Bent double.	Bent double.	
1167 G.	2·20	Would not bend.	43° broken.	Bent double.	Bent double.	
1167 H.	2·24	16° broken.	·32° broken.	Bent double.	Bent double.	
1167 I.	5·60	*Would not bend.	*Would not bend.	15° broken.	16° broken.	*Very brittle.
1167 J.	9·14	*Would not bend.	*Would not bend.	Would not forge.	Would not forge.	*Very brittle.

TABLE V.—*Compression Tests of Aluminium-Steel.*

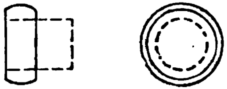
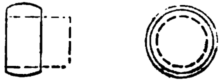
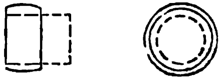
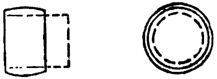
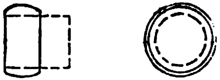
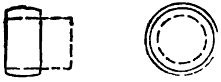
Series and Mark Referred to in Paper.	Al.	Treatment.	Length before being Tested.	Diameter before being Tested.	Total Load Applied per Square Inch.	Reduction in Length by Compression Load of 100 Tons per Square Inch.	Diameter Increased by Compression Load of 100 Tons per Square Inch.	Dotted Lines show Specimens before being Tested. Full Lines show Specimens after being Tested.
			Inch.	Inch.	Tons.	Per Cent.	Inch.	
1167 A.	·15	Unannealed.	·9970	·7970	100	51·00	1·2771	
1167 C.	·66	Unannealed.	1·0025	·7965	100	49·077	1·1735	
1167 E.	1·16	Unannealed.	·9985	·7960	100	47·22	1·1324	
1167 F.	1·60	Unannealed.	1·000	·7972	100	48·10	1·1448	
1167 H.	2·24	Unannealed.	1·0011	·7969	100	45·40	1·1145	
1167 I.	5·6	Unannealed.	·9992	·7966	100	36·57	1·0378	

TABLE VI.—*Water-Quenching Tests of Forged Aluminium-Steel.*

Mark Referred to in Paper.	Al. per Cent.	Treatment No.	How Filed before Treatment.	How Filed after Treatment.	Bending Tests after Treatment.	Remarks.
1167 B.	·61	1	Soft.	No change.	Double [illegible] crack	The untreated forged bending samples of this percentage bent double cold.
"	"	2	"	Shade harder.	Double no cr[illegible]	
"	"	3	"	Hardest of the three, but still quite soft.	Double very slight crack.	
1167 D.	·72	1	Soft.	Slightly harder.	Double cracked half way across.	The untreated forged bending samples of this percentage bent double cold.
"	"	2	"	Slightly harder.	143° broken.	
"	"	3	"	Slightly harder.	133° broken.	
1167 F.	1·60	1	Soft.	Slightly harder.	115° broken.	The untreated forged bending samples of this percentage bent double cold.
"	"	2	"	Slightly harder.	156° broken.	
"	"	3	"	Slightly harder.	121° broken.	
1167 I.	5·60	1	Soft.	Soft.	23° broken.	The untreated forged bending samples of this percentage broke at 15°.
"	"	2	"	Slightly harder than 1.	12° broken.	
"	"	3	"	About the same as 2.	16° broken.	

Treatment
1 = heated to low red heat and plunged into cold water.
2 = heated to bright red heat and plunged into cold water.
3 = heated to welding heat and plunged into cold water.

Note.—These experiments clearly prove that Aluminium, like Silicon, and unlike Carbon, does not confer upon Iron that is Carbonless the property of becoming hardened when quenched in water.

DISCUSSION ON MR. HADFIELD'S PAPER.

Mr. J. E. **Stead** opened the discussion. He said that during the last year and the beginning of the present year, by the direction of the Aluminium Company, London, he had made a large number of experiments to ascertain the effect of aluminium made by that Company upon steel, and also as to the nature of the chemical reaction which took place when aluminium was added to steel. His experiments clearly confirmed what Mr. Hadfield had said —that on adding aluminium to iron there was an increase in temperature. Added to cast iron free from any oxide of iron whatever, the temperature was very materially increased. On adding it to white iron—that was to say, iron which contained no silicon whatever—and adding it in pretty large excess, there was a considerable amount of carbon forced out by the combination with the iron, showing that when iron was combined with aluminium the rejected carbon had no iron to combine with and was expelled. Another proof that iron and aluminium combined chemically was that the specific gravity of the compound was greater than the mean of the constituents; in fact, 77 inches of iron, and 23 inches of aluminium, making a total of 100 cubic inches, before melting together, combined to form a compound of only 97·3 cubic inches.

Now, after having obtained the alloy, the first question asked was how would it behave towards oxidising agents? A cast iron alloy, containing about 8 per cent. of aluminium, about 3¼ per cent. of silicon, and about 3 per cent. of carbon, was melted in a crucible under silicate of iron slag for about an hour. The metal was analysed afterwards, and it was found that 1·8 per cent. of the silicon, and 6·41 per cent. of aluminium, had been taken out, showing clearly that aluminium was much more readily oxidised and removed from its combinations with iron than was silicon. It was, in fact, a powerful reducing agent. It resembled silicon in this respect, but it was more powerful.

After considering this fact for a moment, they would see how utterly impossible it was for aluminium to be found in any steel which had been made by the removal of silicon and carbon from the pig iron by oxidising agents—that was to say, in open-hearth steel or Bessemer steel, which depended for its purification or its manufacture upon the oxidisation of both silicon and carbon by oxide of iron and by air. When the silicon was removed by those oxidising agents, it was impossible for aluminium to be present, because aluminium was more readily oxidised than silicon. Another point of very great interest which had been shown by his experiments was this: that aluminium, when present in steel, or in combination with iron, had power to reduce carbonic oxide. In that respect it was similar to silicon, but it was very much more powerful. He had taken an alloy, containing about 17 per cent. of aluminium, and heated it in an atmosphere of carbonic oxide to a high temperature—insufficient, however, to cause fusion. After heating in this way for several hours, it was observed that when cool, a very dark grey deposit was formed on the outside of the alloy. On scraping it off, it was found to contain carbon, about 16 per cent.; metallic iron, 14 per cent.; and free alumina, 69·6 per cent. Now, that carbon could only have come from the carbonic oxide circulating around the piece, as there was no other source; and as the aluminium was originally uncombined with oxygen, it was naturally inferred that the alumina found must have been derived from the carbonic oxide. As silicides do not behave in that way, he thought they might conclude that it was a very much more powerful reducing agent than silicon. This evidence alone would lead to the belief that if it was carbonic oxide which produced blow-holes in steel, aluminium would produce sound castings and sound steel, and on trial it proved to do so. Every trial that they had made indicated that aluminium was capable of killing the most lively and fiery steel, provided, of course, that there was sufficient added to combine with the oxygen in it. If there was a sufficient quantity, the steel would be absolutely dead, and would flow like the deadest melted silicon steel. His experiments proved that one-tenth of one per cent. of aluminium would be amply sufficient to produce that.

Now, if aluminium would remove oxygen and carbonic oxide from steel, knowing that those elements were considered to be detrimental to steel, they should consider that aluminium would have some beneficial effect. In his trials with crucible steel he thought that that was clearly demonstrated. In order to make the trial as comparative as possible, a large crucible of steel was melted in the ordinary way, and, after being properly melted, one half of it was teemed out into an ingot mould, and aluminium was added to the other half, and that was also cast. The steel produced was tested in every way that he could imagine, viz., for springing qualities, for edge or cutting properties, and for the power to resist sudden shock; for the power also to resist corrosion, for tensile strength, and for elongation. He found that in such tool steels, containing about 1 per cent. of carbon, the elongation and ductility were most materially increased, that the tensile strain was slightly reduced, and that the edge or cutting properties were the same in both steels, that was to say, the two steels, with and without aluminium, were about equal to one another, but the springing properties were materially better in the aluminium steel. The power to resist sudden check or shock was also increased, that was to say, aluminium steel had a higher resistance than that without aluminium.

The bars were tested mechanically, with the following results:—

Tensile Tests of Tool Steel, with and without Aluminium.

Description.	Length. Inches.	Maximum Breaking Strain	Elongation per Cent.	Area before Fracture. Inches.	Area at Fracture. Inches.	Contraction of Area per Cent.
1 N.	6	64·8	4·2	·3217	·2642	17·9
2 „	6	65·3	5·5	·3217	·2827	12·1
Average	6	65·05	4·85	...	...	15·0
1 E.	6	52·6	6·8	·3019	·2642	12·5
2 „	6	51·7	5·2	·3117	·3827	9·3
Average	6	52·15	6·0	...	...	10·9
1 N. + Al.	6	63·5	7·0	·3217	·2734	15·0
2 „ „ „	6	61·9	6·7	·3117	·2552	18·1
Average	6	62·7	6·85	...	...	16·55
1 E. × Al.	6	48·5	9·4	·3217	·2376	26·1
2 „ „ „	6	50·0	13·0	·3217	·2376	26·1
Average	6	49·25	11·2	...	...	26·1

Here a very great difference existed. In the best Swedish steel E., the addition of aluminium had reduced the tensile strength from 52·6 tons to 49·25 tons = 6·4 per cent., and increased the ductility, as indicated by the elongation, from

Before = 5·2 per cent. After = 11·2 per cent.	Increase = 115 per cent.

The difference in the commoner material is not quite so marked.

Tensile strength reduced.	Without 65·05 tons With 62·70 „	3·63 per cent.
Ductility increased	Without 4·85 per cent. With 6·85 „	41·2 per cent.

These tests were obtained from the bars as received from the makers, after turning down to shape for testing.

Aluminium increased the toughness of steel after it was drawn into wire. Very many more twists could be got out of a length, say of 6 inches of wire, when aluminium was present than when it was absent. So far as the corrodibility of the steel was concerned, his experiments had proved clearly that aluminium, although itself not readily corroded in the air, tended to slightly increase the liability of steel to corrode. Aluminium, although a very powerful and very good conductor of electricity, when alloyed with steel in very minute quantities, had its resistance increased from 6 to 12 per cent.

He thought Mr. Hadfield's paper was very admirable indeed, and gave a good deal of valuable information. One question that had presented itself to him in reading the paper was this, that perhaps the comparatively poor result of aluminium in Mr. Hadfield's case in the making of castings was due to the very superior castings that he almost invariably produced in the ordinary way. Now there were many makers of castings who did not make such good and sound castings as Mr. Hadfield did, and to whom, therefore, the use of aluminium would be much more valuable than to him. In a case where aluminium had been added to ordinary open-hearth steel of a soft nature, with properly prepared moulds, the castings had been very sound indeed. The test-bars, which were cast about 8 inches by ¾ square, were perfectly sound, and had a tensile strain of about 20 tons per square inch, whereas the same bar without aluminium only stood about 10 tons, the reason being that in the ordinary steel without aluminium the cavities were great. One-tenth per cent. of aluminium in that casting increased the weight and solidity, and reduced the blow-holes by 23 per cent. Did aluminium make the steel more fluid? He had made some observations to test that point, and would now describe them.

Several experiments were made, of which the following was a type. A piece of flat iron, ¼ inch by 2 inches, was rolled up in a spiral form. This was used as a pattern. Two moulds from this pattern were made, and placed side by side, and two steels, one containing aluminium, and the other not, from the same source, were poured at the same time into the two moulds. The aluminium steel filled a greater length of the mould and was solid, the other being honeycombed. Taking the two pieces of steel, one containing aluminium and one without, and placing them in a crucible and gradually raising the temperature, taking care to observe what took place in the interior, it was found that the steel containing no aluminium began to melt first. What, he asked, was the reason that, although aluminium did not lower the melting-point of steel, it enabled it to flow to a greater distance, and behave as if it did?

In his opinion, fiery honeycombed steel frothed up as soon as it entered the mould, and as there was no body of steel and heat accompanying it, it rapidly set, and prevented further passage of more metal. On the other hand, aluminium steel, being perfectly quiet and in a continuous mass, passed to the extremity of the mould in a stream. He had found that aluminium, added to very high silicon steels which were already dead melted, did not cause it to flow so far as the same steel without aluminium.

That was his explanation of the apparently greater fluidity produced in soft steel by aluminium. It was not greater fluidity, but greater continuity of body and freedom from gases.

The proportion of metallic aluminium sufficient to cause perfect solidity, if added as metallic aluminium and not as an alloy, and just before it is moulded or cast, should not exceed one-tenth per cent. at the outside, five hundredths being generally found sufficient. Some investigators held that this amount was insufficient, but he thought that in making their experiments they were not aware of the extreme rapidity with which aluminium is oxidised, and had probably kept the aluminium steel in the furnace or crucible too long before tapping, allowing time for the aluminium to disappear.

Mr. E. P. **Martin** said that Mr. Hadfield's paper stated that "these special steel or alloys, such as silicon, manganese, or chromium steel, have slight if any welding properties." He should be very glad if Mr. Hadfield would add to his most valuable paper any information which would enable them to know what facilitated the welding properties of steel. He had always thought—but perhaps he was mistaken—that the presence of manganese assisted considerably in making the ordinary Bessemer or Siemens steel weldable.

Mr. P. C. **Gilchrist** said that two or three years ago he made some experiments with alloys of iron and aluminium, manganese, and carbon. He commenced with the purest iron he could get, that is to say, he took as the material to which the aluminium was added the iron got in blowing basic iron before the ferro was added. He was sorry to say that he thought that paper was intended to be read in London in May, and so he had not brought the results of these experiments with him. He could, however, tell them roughly the gist of them, and before the Proceedings were published he would send those results to their Secretary carefully arranged. The reason that he had not published them was that he had not been able to arrange them to his satisfaction. He could not prove the point that he wanted when he started the experiments, and he was not able to arrange matters as clearly as Mr. Hadfield had done, but he thought that he would be able to classify them in an interesting manner, now that the author had started a scheme, when he thought it would be seen that they confirmed most of Mr. Hadfield's points. He should mention that he was indebted to Mr. Seaman of Sheffield for melting pure iron and pure aluminium to make the various alloys of iron and aluminium alone; of iron, aluminium, and manganese; and of iron, aluminium, and carbon. He started out to see if aluminium would replace manganese entirely, that is to say, whether it would take away the red-shortness of the iron at the end of the Bessemer operation, or at the end of the Siemens operation, and he found that it would not. If he had merely iron and aluminium, it would not work, and it was necessary to have a small amount of manganese. The presence of aluminium would reduce the amount of manganese that was required, but it would not replace it entirely. He thought that was all he was prepared to say from memory. The other points he could bring out in the notes that he would send to the Secretary for publication.*

Mr. HADFIELD, in replying, said he was glad to know that Mr. Stead agreed with him as to the material described in the paper being a compound, and not an alloy. Mr. Stead stated that he considered aluminium to act more powerfully than silicon.

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* Mr. Gilchrist's notes, subsequently sent in for publication, are appended :—

A considerable number of experiments were made in order to test whether and to what extent manganese could be replaced in ingot iron by aluminium without fear of red-shortness.

The aluminium was added to blown metal from the basic converter.

As a result of the experiments, it was shown clearly that aluminium has no influence in removing or preventing red-shortness. Its action on the mechanical properties seems to be to increase slightly the ultimate tensile strength, at the same time also increasing the elongation.

Samples prepared with 0·2 per cent., 0·5 per cent., and 0·7 per cent. of aluminium (the manganese being 0·10 per cent., 0·19 per cent., and 0·18 per cent. respectively), all refused to roll. A sample prepared with 1·12 per cent. of aluminium and 0·19 per cent. of manganese rolled well; but the blown metal to which no aluminium was added rolled equally well, so that the freedom from red-shortness cannot in this case be attributed to the presence of aluminium.

To show the influence of a comparatively high percentage of aluminium on soft steel, the following series of tests may be cited :—

Sample.	Analysis.						Mechanical Tests.			
	Si.	P.	Mn.	C.	S.	Al.	Ultimate Stress per Sq. Inch.	Elongation on 8 inches.	Reduction in Area.	Remarks.
							Tons.	P. Cent.	P. Cent.	
A ...	...	·075	·198	·05	·04	1·12	31·0 28·7	24·3 24·8	67·4 69·3	As rolled, annealed, and quenched.
B Blown metal to which Al. added in experiment	...	·040	·140	·05	·05	nil.	26·3 27·4	20·0 18·6	69·9 65·1	As rolled, annealed, and quenched.
C ...	...	·061	·196	·05	·033	2·75	35·0 32·1	12·9 19·8	30·7 37·7	As rolled, annealed, and quenched.
D Blown metal to which Al. added in experiment	...	·061	·190	·06	·033	nil.	27·1 32·1	19·9 16·4	70·2 52·5	As rolled, annealed, and quenched.

According to the pamphlet published by the Alliance Aluminium Company, their statement seemed to prove the contrary, viz., that silicon was more powerful than aluminium in absorbing gases, which was the principal point to which a steel-founder looked.

He could not help thinking that if it were possible to obtain pure silicon, or, say, an alloy of 98 per cent. purity, they would find it quite as efficacious an addition as aluminium; but of course such an alloy was practically unobtainable at present. It would be interesting to test this point, if some of their friends who made aluminium would try also to make pure silicon. Seeing also that silica, the base with which they would start in the manufacture of such a product, was so much cheaper than alumina, it might be worth while to investigate the point. Mr. Stead had stated that he considered as small an amount as 10 per cent. quite sufficient to produce soundness. He could only say with reference to this, that Mr. Keep, of Detroit, Michigan, who had made a considerable number of experiments as to the effect of aluminium upon both cast iron and steel, considered that such an amount would be quite insufficient; and he must say he was rather inclined to agree with him. Mr. Keep had said that as much as 75 per cent. would be requisite to secure uniform soundness; and even with aluminium at the price of 6s. per lb., this would mean an increase in the cost of £4 per ton; not a satisfactory item in a steel-founder's material bill.

Mr. Stead had also mentioned that he considered that aluminium increased the fluidity of steel; but he thought Mr. Stead's explanation should also be borne in mind, viz., that his experiments were with reference to *frothy* steel, that was, steel which, to start with, was unsound. Now a good steel-founder would not use such steel to put into his castings at all, apart from the question of using or not using aluminium; so that Mr. Stead was evidently looking at it from quite a different point of view to that of a steel-founder.

As to Mr. Martin's remarks, he certainly thought that the greater the percentage of foreign elements present in steel, the more difficult would be the welding process. His own observations indicated that both silicon and manganese hindered good welding results—that was, when the manganese was in excess of 1 per cent. That was especially proved in manganese steel manufactured by the speaker's firm (Hadfield's Steel Foundry Co., Sheffield), containing about 9 to 14 per cent. of manganese, which was practically unweldable. Even the electric welding system had failed to make a satisfactory weld.

He had just had a conversation with Professor Thomson, who thought that with the later machines they might be successful; but in any case there would be much difficulty experienced. Speaking on this question, there must be a great future for electric welding, because it treated the material to be heated in quite a different manner from that now employed; and for this reason, if any system could give successful results in welding these special alloys, or compounds of iron, with manganese, silicon, chromium, nickel, &c., Professor Thomson's was the most likely. But he certainly thought that, as regards steel, the more nearly the material under examination consisted of iron, the better the weld, and the more foreign elements present, the more difficult it would be. His own attempts to weld aluminium steel were unsuccessful, although the samples were given to a clever blacksmith, who did his utmost by several trials to attain the desired result.

In conclusion, he regretted that more remarks had not been offered, as the question of obtaining homogeneous and sound steel was of the greatest importance not only to steel-founders, but to manufacturers of ordinary steel.

The PRESIDENT said that Mr. Hadfield had been labouring in that field of research for many years, and had been very open and very continuous in communicating to the Institute the results of his labours. He thought they would all agree with him that the Council had been only just in recognising those labours, and only wise in seeking to enlist in their service some of the rising talent of the Institute by nominating Mr. Hadfield for a seat on the Council. He proposed that the best thanks of the meeting be given to Mr. Hadfield for his paper.

The motion was then put to the meeting, and was adopted by acclamation.

CORRESPONDENCE.

Mr. THOMAS ANDREWS, F.R.S.: I have read with great interest the admirable paper by Mr. R. A. Hadfield on aluminium steel. There can be no doubt but that aluminium will play a very important part in the metallurgy of steel in the near future. I am at present engaged in studying the influence of aluminium on the passivity of steel, in the course of my research on the passivity of iron and steel for the Royal Society, and I anticipate some interesting results, though at the present juncture it would be premature to give them. The high-percentage aluminium steel on which I am working has so far shown somewhat brittle properties, and in course of rolling the ingots into small bars many of the latter have broken in the process. It has so far also been found very difficult to draw the small rolled rods cold through a wortle. Although my research is yet incomplete, I may perhaps say that the aluminium steel, as regards its passivity, has hitherto behaved somewhat differently in comparison with the behaviour of ordinary cast steel—Siemens, Bessemer, manganese, nickel, tungsten, and other steels; but on this point I hope to have more to say when my investigation is complete. I congratulate Mr. Hadfield on the excellent and valuable results he has already obtained in connection with the study of aluminium steel, and heartily wish him every success in his future investigations.

Mr. F. OSMOND (Paris): Mr. R. A. Hadfield has studied the action of aluminium in the metallurgy of iron in the admirable manner that characterises all his work. His researches enable industrial questions to be satisfactorily solved by the aid of the exact processes of the physical sciences. There consequently remains but little to say after him; and, as the author has shown in his paper, I am pleased to be completely in accord with him on all the points concerning which I have been able to form an opinion of my own.

From an industrial point of view, it appears to be well proved that aluminium is, like silicon, a reducer of oxide of iron. Anhydrous silica, obtained from amorphous silicon, is formed with a liberation of 219·24 calories, according to Troost and Hautefeuille, and aluminium hydrate $Al_2O_3 + 3H_2O$ is formed with a liberation of 391·6 calories, according to Thomsen. Hence it is deduced that if the heat of hydration of the alumina (not known, and probably very insignificant) is neglected, 16 of oxygen liberate 109·6 calories on combination with silicon, and 130·5 calories on combination with aluminium. Thus, according to the indications of thermal chemistry, aluminium is a still more energetic reducer than silicon, not for equal weights, but in the presence of the same quantity of oxygen. In other words, aluminium would be burnt before silicon in intermolecular combustion, in so far as it is allowable to state this without more complete data. In such a case there would be a slight advantage in favour of aluminium, an advantage, however, that the present price of aluminium, in spite of its enormous fall during recent years, would render very expensive.

It can merely be asserted that aluminium, when met with in steel in small quantities, furnished without expense by the hearth, appears to be indicative of good quality, not on account of the limited influence that it exercises on the properties of iron, but as evidence of a well-conducted charge on the open-hearth. If, in fact, an element so easily oxidisable has been able to retain the metallic state, it is probable that the bath itself has experienced the minimum amount of oxidation, and has yielded sound ingots.

From a scientific point of view, the samples obtained by Mr. Hadfield might be, and have already been, the object of interesting researches. If the curve of cooling of the alloy containing 5 per cent. of aluminium is examined, and compared with that of an extra soft steel, containing nearly the same percentage of carbon,* it will be seen that the point d_{r3} is wanting. The aluminium thus maintains the iron, for the most part, in the α-state from the ordinary temperature to the melting-point. This explains why annealing effects no notable change in the structure, as Mr. Hadfield has shown, and also why the structure, at the same temperature of annealing, differs completely from that of ordinary mild steel.

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* *Journal of the Iron and Steel Institute*, 1890, No. I. p. 43, Plate III.

For the same reason, if a sufficient quantity of aluminium is added to a bath of molten steel which is in the β-state, the β-iron will be transformed into the α-modification,—a change which liberates a considerable quantity of heat. In this way I should explain the phenomenon of coruscation observed by Mr. Hadfield.

If my interpretation of the phenomena is accurate in all points, steel with 5 per cent. of aluminium should present another curious peculiarity—that of remaining magnetic at all temperatures. This is, however, a theoretical deduction, which consequently requires to be proved by experiment. I should be pleased if Professor Barrett, or Dr. Hopkinson, whose former researches have so important a bearing upon scientific metallurgy, would direct their attention to this question.

Mr. Hadfield's paper also brings into notice the question of the determination of aluminium in iron. This presents, at least in so far as it deals with very small quantities of aluminium, a difficult problem in analytical chemistry, and I have good reasons for believing that in many cases the aluminium that has been found in certain steels has been derived from the glass vessels used, or from impurities in the reagents. A general paper on this subject would be of great interest. Personally, I have had occasion only to occupy myself with the matter incidentally. The method that I adopt is as follows:—The steel cuttings are first heated to redness in a current of hydrochloric acid gas, as is the case in the classic method proposed by Boussingault for the determination of silicon. When the steel contains aluminium, this element remains with the silicon in the white residue, in which a certain quantity of phosphoric acid also remains. The weight of the residue gives the total of the three substances. The silicon alone is then determined by Drown's method, and the phosphoric acid is determined in the residue. The methods of Boussingault and Drown are sufficiently accurate in the hands of a good chemist to enable the alumina to be determined by difference. Further, the presence of phosphoric acid guarantees that of aluminium, and it is always possible, as a check, to separate by the usual methods the silica and alumina in the residue obtained by Boussingault's method. All the iron having been eliminated, this separation demands only a very small quantity of reagents, and can be made with precision, provided that care is taken to exclusively employ platinum vessels and well-tested reagents.

I conclude these remarks by thanking Mr. Hadfield for the place which he has kindly given in his paper to the experiments he was good enough to allow me to make with his samples.

Mr. JOHN H. J. DAGGAR, F.I.C., F.C.S.: In taking part in this discussion, let me first thank Mr. Hadfield for his very interesting sketch of the early history and properties of aluminium and the present-day processes for its production, and then let me enter a protest against any attempt to alter its name. All metals discovered in modern times have been given Latinised names terminating in *-ium,* the non-metals or metalloids in *-ion,* and, in accordance with this accepted nomenclature, silic*ium* has been changed to silicon, selen*ium* to selen*ion,* both these elements being distinctly non-metallic. The objection to "alumina" will hardly stand, unless one is prepared to accept also sod*ia,* potass*ia.* To give the distinctly metalloidal termination *-on* to an element with the most marked characteristics of the metal, totally differentiated from the metalloid silicon, would only introduce needless confusion into chemical nomenclature.

According to Gautier, ferro-silicon has been used for some years past in French foundries for the prevention of blowholes in steel castings, and much has been done to extend its use in this country by the work and experience in this direction of Mr. Turner, Mr. Hadfield, and others; and there is no doubt at all that very great benefit has been derived from the judicious use of aluminium, though of course steel manufacturers are naturally very reticent as to the results actually obtained; but the elaborate and careful researches of Keep and others have thrown very much light on the exact influence of aluminium on cast iron, and the limits of its use, and repeated experiments have shown that it is equally valuable in steel manufacture. In an experiment brought under my own notice with basic Siemens-Martin steel, the tensile strength was increased from 98,560 lbs. to 112,000 lbs. by the addition of 0.2 per cent aluminium.

Chemical Action.—From my own experience with alloys of aluminium and iron, I have scarcely any doubt but that aluminium combines chemically with the iron; the addition of aluminium to molten iron in the crucible being accompanied by phenomena closely resembling that occurring in the formation of the copper alloy.

Fluidity.—The extra heat evolved during the union of the two metals is, however, in my opinion, insufficient to account for the increase of fluidity followed by rapid setting. The experiment by Mr. Osmond, quoted by Mr. Hadfield, disproves the theory as to the lowering of the melting-point. The great affinity of aluminium for oxygen renders it exceedingly probable that Ledebur's theory is correct; and in this connection aluminium would be far superior to silicon. One word as to the affinity of silicon and aluminium for oxygen. The point bearing upon this question is not the weight of oxygen which will combine with these two elements, respectively, but the readiness with which oxidation will occur.

Silicon which has been strongly ignited in a covered crucible does not oxidise in the oxyhydrogen flame, or on fusion with nitre, though the amorphous silicon readily does so. Aluminium, on the other hand, absorbs oxygen readily when heated above its melting-point in contact with bodies containing oxygen, and will reduce SiO_2, forming Al_2O_3, liberating Si. $4Al + 3Sio_2 = 2 Al_2O_3 + 3Si$.

The effect of aluminium in diminishing hardness is doubtful. An ingot made from pure aluminium and hæmatite iron containing 15 per cent. to 16 per cent. aluminium, cast in the chill, was only marked by the file with very great difficulty, great force being required to chip it; the fracture was close, fine, and crystalline. Another sample of aluminium steel, containing 7 per cent. aluminium, with 1–2 per cent. manganese, will just scratch glass.

The soft nature of aluminium itself does not affect this question, for its addition to copper gives alloys which are glass hard. Its influence on iron in this direction, used as it is in small proportions, will depend entirely upon the change it produces in the state of the carbon present.

Magnetism.—Above 5 per cent. aluminium rapidly destroys the magnetic properties of iron, and some time ago experiments were carried out to determine whether this phenomenon would furnish a clue to the percentage of aluminium present; but the results then obtained were not precise enough for quantitative indications.

The action of aluminium resembles that of silicon, and is probably as follows:—(*a.*) Its action on the combined carbon. (*b.*) Its action on dissolved oxides of iron. (*c.*) Decomposition of gaseous and solid compounds of carbon and hydrogen entangled in the molten metal, and possibly also of brittle combinations of carbon and iron.

The action of aluminium is more certain to produce sound ingots than by the use of silicon, as indeed one would expect, aluminium forming a true alloy with the iron, and alloy being taken to mean the union of two metals. Silicon *alloy* is a misnomer; though often used for convenience, silicon is not a metal.

To conclude, Mr. Hadfield's paper has undoubtedly proved the great value of aluminium to the steel-founder, and contributed much to the somewhat meagre knowledge of aluminium alloys. In his comparison of this element with its rival silicon, his only objection to its use has been the additional cost. From my own knowledge of the use of aluminium, I can only repeat that the more certain results obtained with smaller amounts of aluminium will more than compensate for the extra cost in the finer quality of castings produced.

M. Alexandre Pourcel: Although Mr. Hadfield's interesting paper on aluminium steel does not solve all the obscure points relating to this subject, it goes a long way towards explaining the action of aluminium in steel. Professor Ledebur of Freiberg was the first to contest that aluminium lowered the melting-point of steel. The fluidity that is imparted to steel by the addition of only $\frac{1}{1000}$ of aluminium is due, according to Professor Ledebur, to the disappearance of every trace of ferric oxide and slag from the intermolecular spaces, under the energetic influence of aluminium as a reducing element. In my opinion, however, the cleanliness of the bath is not the only cause of its fluidity, provided that manganese silicide, possibly also clean without being fluid, has been added to the bath. The researches of Mr. Osmond prove that the melting-point of a steel with 5·60 per cent. of aluminium is at most 25° C. lower than that of an extra mild steel without aluminium. Professor Ledebur's opinion is thus confirmed by experiment: aluminium does not lower the melting-point of steel. Besides, however, the action as a reducing agent that that experiment proves aluminium to have, there must also be recognised that of a calorific agent. In this connection Mr. Hadfield does not deal with the question in its true light. According to Berthollet, he points out that the change of the unit of aluminium into Al_2O_3 liberates 7900 calories, and that of the unit of silicon into SiO_2 liberates only 7800 calories. The difference is not very considerable, and as $\frac{2}{1000}$ or more of silicon is usually added, the question arises why a more fluid metal is not obtained with silico-spiegeleisen than with $\frac{1}{1000}$ of aluminium? The confusion made by Mr. Hadfield, and by many others with him, is to attribute the same calorific power to silicon in the state of silico-spiegeleisen or manganese silicide—in fact, in an alloyed state, as in the state of purity. This is an error, a grave one, that I pointed out ten years ago, and that I shall continue to emphasise until the honour is done me to seriously discuss, after reflection, the opinions I set forth in my paper on the applications of thermo-chemistry to metallurgical reactions. 1. The calorific power of silicon in the state of alloy cannot attain one-half of that of pure silicon according to the richness of the alloy. 2. As the alloys of silicon are usually employed in the solid state, account must be kept of the heat absorbed by the bath to melt them, or, in other words, of its calorific capacity. 3. Lastly, the oxidation of the alloy with silicon gives rise to a slag, the calorific capacity of which, determined by the researches of Professor Gruner, of Sir Lowthian Bell, and of other investigators, greatly exceeds that of the metal. Indeed, it may be asked whether the total of these intermolecular reactions has not contributed to lower rather than to raise the temperature of the bath of metal.

With aluminium, on the other hand, and especially with aluminium commercially pure, containing 98 per cent. of aluminium, which is employed in most foundries, and which melts between 600° and 700° C., it may be admitted that all the heat liberated by its change into alumina, or, in most cases, the greater part of this heat, is added to that of the bath of steel. There is a reheating of the steel. By utilising the heat added to a bath of mild steel by the addition of $\frac{1}{1000}$ of pure aluminium, I have been enabled to produce recarburised steels containing chromium, nickel, or tungsten, in which, thanks to the fluidity of the metal, perfect homogeneity is preserved.

Mr. J. H. Darby: As far as my experience goes, aluminium is useful to those who make castings for themselves, as, by its use, metal of almost any temper can be used, and the castings made therefrom in the majority of cases do not require annealing, and, with very little care in teeming, are quite sound. No doubt excellent castings can be made by firms who work day after day on metal suitable for castings, but where a charge is only occasionally required, a small addition of the metal aluminium, about one per cent., enables you to get perfectly sound castings. The metal, however, "pipes" badly, and requires a large head to feed the castings from. The great disposition to "pipe" in metal to which aluminium has been added will, in my opinion, always prevent its use in the manufacture of solid ingots. I have seen them with a considerable hole caused by contraction which continued for three-fourths of the length of the ingot from the top.

Aluminium is useful by its absence, *i.e.*, its avidity for oxygen contained in the steel at once converts it into alumina, which I have frequently picked out of any small irregularities that may exist on the surface of ingots when cool where aluminium has been added to the steel. The ingots are so marked with these thin patches of alumina that it is quite distinctive, and is not to be confounded with wash off the mould. In fact, there is just as much on ingots from perfectly clean moulds.

My experience goes to prove that what I have stated above shows there is practically only one kind of gas absorbed or occluded by molten steel, and that is carbonic oxide. Remove the oxygen completely, as is possible with aluminium, and the metal, Bessemer or open-hearth, acid or basic, is perfectly quiet and absolutely solid, whether hard or dead soft.

A peculiarity I have noticed, and am not quite able to account for, is, that although molten steel may be completely deprived of oxide by aluminium, still it will fall to pieces, and will not "work," unless it contains a small percentage of manganese. Possibly in the latter case the small percentage of sulphur always present causes red-shortness.

Mr. W. S. **Sample** (of the Metal Reduction Syndicate): I have read the paper on aluminium steel by Mr. R. A. Hadfield with much interest. I cannot give a report based on my own observation, but since we have begun the manufacture of aluminium, we have supplied a great many steel-makers; and, by their continuing the use of the metal, we are led to believe that they are getting satisfactory results with the use of the metal in steel castings. These have not been merely trial orders for experiment, as orders have been duplicated and increased. The benefit of using aluminium is not confined to steel for castings alone. A careful series of experiments as to the effect of aluminium in mild open-hearth steel has shown that the addition of about half a pound of pure aluminium to a ton of steel has a markedly quieting effect on the steel, produces sound tops to the ingots, and, consequently, less percentage of scrap in rolling. If too much aluminium is added, it will cause piping. Professor John W. Langley, of the Crescent Steel Works, Pittsburgh, Pennsylvania, allows me to say on his behalf that the saving by the use of aluminium is such that no steel-works can afford to do without using it, at the low price at which it is now sold. Of course, experience is a great factor in determining how the aluminium shall be used. The aluminium should be added to the ladle as the metal is being tapped into it. Should the steel be very "gusy" or "wild" in the ladle, up to two or three pounds should be added per ton of steel in order to quiet the metal, and for such "wild" heats, aluminium should be in hand at every furnace. The two extremes are too much and too little, and the best results have shown that about half a pound of aluminium per ton of steel will save far more than the cost of the aluminium by the decrease in scrap in rolling. We do not want to make steel-makers believe that aluminium is a panacea for all the ills, but when so many users are continuing, and report benefits, it is very good testimony.

Mr. Sample adds that he has not exhausted the subject, from his point of view, in these remarks, but he had had much pleasure in adding these remarks to the discussion of Mr. Hadfield's paper.

Mr. T. **Turner** (Mason College, Birmingham): I have read Mr. Hadfield's paper with great interest, and feel that this last contribution greatly increases the obligation which those who are interested in the connection between the chemical and mechanical properties of iron and steel already owe to the author. Probably, however, few chemists would at present approve of the suggested alteration in the name of the metal aluminium, even if it were practicable, for though the name now in use is not euphonious, the suggested change would class aluminium with carbon, boron, and silicon, all of which are decidedly non-metallic in character. The American termination of *-um* is perhaps, on the whole, the best, as the characteristic metallic properties of aluminium more resemble those of ferrum, cuprum, aurum, and argentum. The close resemblance which Mr. Hadfield has shown to exist between the effect of silicon and aluminium on the properties of iron and steel is perhaps the most important outcome of his researches, and should do much to moderate the sanguine anticipations of some inventors who claim so much benefit from the use of aluminium. Mr. Hadfield was good enough to send me some samples of steel, containing various proportions of aluminium, to be tested for relative hardness, and the results of my tests fully corroborated the statements made in this paper, that little or no real hardness is conferred by aluminium. A short time before Mr. Hadfield's paper was written, I was consulted in connection with a recently introduced process for producing aluminium steel, and a number of samples were submitted to me for examination. Some of these were beautifully polished, and exhibited a most brilliant lustre, while most of them were unusually hard. It was believed that the aluminium, which it was stated these samples contained, was the cause of the unusual lustre and hardness. I ventured at the time to cast very serious doubts upon this matter, and to suggest that the properties above mentioned were such as could be accounted for by the known composition and method of production of the steel, quite apart from the presence of aluminium. I am now indebted to Mr. Hadfield for the more complete and exact knowledge furnished in his paper, which confirms and amplifies the views on this matter which I previously expressed. So far as our knowledge goes at present, it appears to me that the greatest opening for the application of aluminium in the iron trade is for special purposes in the foundry for producing grey iron, and occasionally in steel for obtaining soundness. But it is evident that before aluminium can be of much use to the iron manufacturer, the cost of production must be even further considerably reduced.

Professor J. O. Arnold (Leeds): Mr. Hadfield's research must be regarded as a most valuable addition to the literature of what may be termed the pure metallurgy of iron. In it he has shown to perfection the mechanical effects produced by the addition of varying percentages of aluminium to wrought iron or very mild steel. The results of his experiments, however interesting from an academical point of view, have little bearing upon the commercial production of crucible steel and steel castings, because the difficulty of melting and teeming so mild a material, and the consequent wear and tear of refractory material, place it out of court as an everyday product, capable of being manufactured in large quantities.

The writer, assisted by the demonstrators and students of the Sheffield Technical School, has been engaged for some time upon a careful investigation of the effects of aluminium applied to the manufacture of tool-steel and steel castings, as produced in ordinary practice. The results obtained are extremely remarkable and interesting, and will, I believe, inaugurate a new departure in the manufacture of such steels. The detailed results of the research will form the subject of the inaugural lecture of the Sheffield Technical School Metallurgical Society, but, by permission of the Council of that body, the following preliminary and abridged statement is made to the Iron and Steel Institute. The results of repeated experiments have:—

(1.) Fully confirmed Mr. Hadfield's observations, that no general rise of temperature accompanies the addition of aluminium to molten steel, but that, if anything, the metal is rendered less fluid.

(2.) Induced the writer to altogether dissent from Mr. Hadfield's view, that the action of aluminium is an analogue of that of silicon. His (the writer's) experiments show clearly that the effect of even small quantities of aluminium in producing steel free from blow-holes is perhaps the most remarkable phenomenon in the metallurgy of steel. Its action is about twenty times as powerful as that of silicon, and the resultant steel is far superior in ductility and toughness to steel rendered sound by the addition of silicon, when due precautions are taken to avoid the danger attending its use mentioned under heading 4. (*Vide infra.*)

(3.) Proved that the action of aluminium is almost certainly chemical. The writer has not yet completed this branch of the research, but the results so far obtained are as follows:—

That blow-holes proper are due to the non-oxidising occluded gases, hydrogen, carbonic oxide, and nitrogen, separating (under a pressure of many atmospheres) from the steel just prior to solidification. It has been proved by repeated experiments, made in a specially-constructed tube furnace, that *metallic aluminium readily decomposes carbonic oxide below steel-melting heat, with formation of alumina and free carbon;* in other words, the most powerful reducing gas known to metallurgists acts, in the case of aluminium, as an oxidising agent. To confirm this reaction, under the exact conditions of steel manufacture, the writer blew 40 gallons of pure carbonic oxide through a crucible of molten steel containing aluminium, and obtained an increase of 35 per cent. on the carbon present before passing the gas.

(4.) Indicated that the addition of 0·05 to 0·1 per cent. of aluminium causes mild crucible steel (carbon, 0·5 per cent.) to "pipe" freely, the cubic capacity of such pipe representing the contraction of the liquid metal occurring between the molten and pasty conditions. In the case of "blown" steel no such piping is observed, because the separation of gas bubbles more than counterbalances the contraction. In both ingots and castings piping has to be guarded against by special precautions, which will be dealt with in the main communication.

The writer has here to record the important result of the first practical application of Sorby's method of microscopically examining steel. It will be obvious that steel from which the occluded gases are removed, or do not separate, will be very susceptible to linear contraction. The disastrous effect of this, in the case of castings of certain shapes firmly embedded in rigid "compo," is well known to steel-founders from the fact that such castings are sometimes "pulled" in two.

A careful microscopical examination of the phenomenon of "pulling" has revealed the alarming fact that incipient pulling may exist which is quite invisible to the eye, even when aided by a powerful hand lens.

Polished test-pieces which appeared absolutely free from fluids were turned from such castings, but on testing they stood less than half the maximum stress usually associated with their chemical compositions; and the fractures showed dark patches, some of them a quarter of an inch in diameter, where the air had penetrated and oxidised the crystals through microscopic fissures $\frac{1}{5000}$ to $\frac{1}{10000}$ of an inch in breadth.

All steel which has been unduly strained in tension whilst hot is permeated with these fissures, which may or may not be in communication with the atmosphere, but which, in any case, weaken the steel to a great extent. How far these conditions may obtain in *forgings* containing parts of a highly unequal mass is a matter for further research. Another interesting point is whether or not the remarkable increase in toughness and capability of resistance to shocks obtained in annealed over unannealed castings is due in some measure to the closing up and welding of these contraction fissures.

5. Shown that the addition of 0·05 of aluminium to high-class crucible steel ingots, cast in such a manner as to avoid the evil of "piping," will bring about the following important results:—

(*a*.) Dispense with the addition of manganese, and so produce the ideal iron and carbon steel.

(*b*.) Do away with the necessity for "wash-welding."

(*c*.) Save 25 per cent. of the time and fuel respectively occupied and used during the operation of "drilling," together with the resultant saving of wear and tear to crucible and furnace. A pure steel, lower in silicon and manganese than that at present produced, will thus be obtained, with a saving of some shillings per cwt.

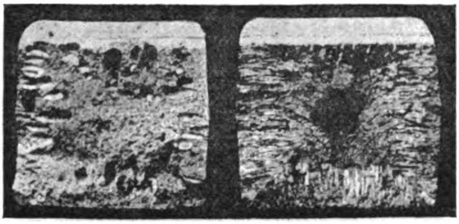
EXPLANATION OF PHOTOGRAPHS, SHOWING COMPLETE ELIMINATION OF BLOW-HOLES.

FIG. 1.—*Transverse Fracture of Ingots.*

A. Melted from LSS converted bar melted with 0.6 per cent. and 80 per cent. ferro-manganese. Ingot supposed to be "killed." No piping precautions. Teemed "fiery." Composition: C.c. 0·99, Si 0·14, Mn 0.39, S 0·02, P. 0.02.

B. Same as A, with the addition of 0·1 per cent. Al, five minutes before pulling out. No attempt made to kill the steel, and no precautions taken to prevent "piping." Teemed quite "still." Composition: C.c. 0·96, Si 0.10, Mn 0·42, S 0·02, P. 0·02. Al not estimated.

FIG. 1.



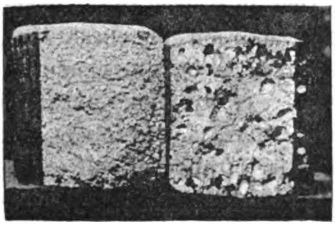
A B

FIG. 2.—*Transverse Fractures of Ingots.*

A. Melted from LSS converted bar without addition of manganese, without killing, but with addition of 0·1 per cent. Al just before teeming, and precautions taken to prevent piping into body of ingot by means of a core or "dozzler." Teemed quite "still." Composition: C.c. 0·97, Si 0·06, Mn 0·05, S 0·02, P 0·02. Al not estimated.

B. Same as A, but no Al added, and no piping precautions. Seemed "fiery." Composition: C.c. 1·04, Si 0.08, Mn 0·06, S 0·03, P 0·02.

FIG. 2.

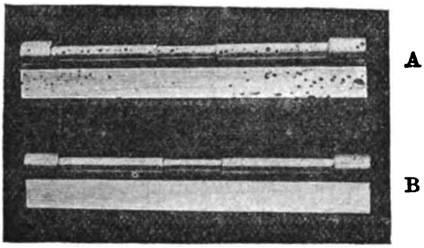


A B

FIG. 3.—*Tensile and Bending Test-Pieces from Dry "Compo" Castings.*

A. Melted from Bessemer spring scrap only. Composition: C.c. 0.62, Si 0·27, Mn 0·46, S 0·11, P 0·08.

FIG. 3.



B. Exactly same as A, but 0·1 per cent. Al added five minutes before casting. Composition: C.c. 0·64, Si 0·29, Mn 0·62, S. 0·10, P 0·8, Al 0·04.

The writer hopes, upon some other occasion, to lay before the Institute the results of the application of aluminium to open-hearth steel, for which he anticipates a great future.

Mr. LE CHATELIER writes that he has not had occasion to make any experiments with the alloys of iron and aluminium. He is of opinion, however, that, in respect to the lowering of the melting-point of iron by the addition of aluminium, some interesting deductions may be made from the general laws of chemistry. Metallic alloys behave exactly like mixtures of salts *per se*, or mixtures of salts with water, that is to say, solutions. By adding to a salt a small quantity of another salt or of water—by adding, for example, a small quantity of salt to ice—the melting-point of the ice, or of the salt that is in excess, is *always* lowered. For the mixture of two bodies in variable proportion, for example, potassium nitrate and sodium nitrate, the curve of the melting-points starting from the pure salts (about 350°), gradually descends, and for a certain intermediate value reaches a minimum (about 200°). In the case where the two bodies can form a stable compound of definite proportions in the molten mixture, the form of the curve may be more complicated, a cusp in the curve being formed at the point where the combination occurs. In all cases, however, the melting-point of each of the two bodies is lowered by the addition of a very small quantity of the other, whatever may be its melting-point. Thus, potassium sulphate, which melts at 1045°, lowers the melting-point of ice.

It is exactly the same in the case of metals. The addition of a small quantity of one metal to another always lowers the melting-point of the latter, the mixture of lowest melting-point being the alloy without liquation. The curve of fusion of the alloys of lead and tin is analogous to that of the mixtures of alkaline nitrates. The alloys of platinum and tin give, on the other hand, a minimum very close to the melting-point of tin, but always lower than it. It is thus certain, without experimental evidence, that the addition of small quantities of aluminium to steel lowers its melting-point. It is merely necessary to know the degree to which it is lowered. This may be calculated in the following way:—

The lowering of the melting-point Δt is given by the formula

$$\Delta t = \text{K.T.}n.$$

where T is the absolute temperature of fusion

$$\text{T} = t + 273$$

or 1773 in the case of iron; n the number of molecules of the metal in small quantity that is added to 100 molecules of the metal present in greater quantity. The molecular weight of aluminium is 27·5, and that of iron is 28. For the alloy with 5 per cent. of aluminium, the value of n is therefore equal to 5. Lastly, the value of K, deduced from the experiments of Messrs. Heycock and Neville,* would be $\frac{5}{1000}$. Whence it may be deduced that the lowering of the melting-point,

$$\Delta t = \frac{5}{1000} \times 1773 \times 5 = 43^\circ.$$

This calculated result does not differ from that obtained experimentally by Mr. Osmond, more than to a degree compatible with experimental error.

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* *Journal of the Chemical Society*, vol. lvii. pp. 376, 656.

Mr. J. W. **Spencer**, of Newburn Steelworks, Newcastle-on-Tyne, sends the following communication:—

I beg to enclose results of experiments on the use of aluminium in the manufacture of steel castings, with the chemical and mechanical tests of the same.

In conducting the experiments, I had chiefly in view the effect of aluminium on the prevention of blow-holes, the mechanical test being subordinate, though important. I therefore used in the melting mixtures of steel such as come to hand, as would be done in a usual way, and in the production of ordinary steel, as distinguished from "steel castings," and the methods used to ensure soundness in them.

The result has been satisfactory in every instance, so far as soundness and the usual attributes of a good casting are concerned, running fluid and without ebullition into sharp clean castings; the milder mixtures, when tried by the hammer-test, breaking very strong, though unannealed.

The chemical reaction of the aluminium in the crucible in presence of other combinations may be various, but reducing the carbonic oxide and preventing blow-holes are the chief desiderata. In claypots the aluminium may react upon the silica reducing it—the silicon going into the steel, especially in presence of high carbon, which of itself generally increases the silicon contents in the steel made in ordinary crucibles.

The present experiments, however, have not been conducted with such nicety as to enable a scientific analysis to be made of the various reactions taking place in the different mixtures; but it will be observed, in looking over the analyses, that there is a marked increase of silicon in presence of the higher percentage of aluminium and carbon.

All the low carbons, A 1, 4, 10, 13, were obtained by using Swedish iron alone, as also A 7, 14, 15. Though A 7 with carbon = ·28 per cent. has a tensile strength of 25·58 tons per square inch, as against A 15 with carbon = ·29 per cent. and 23·62 tons, it may be said that aluminium has increased the elastic limit and tenacity by 2 tons; but it will be noticed that silicon is 0·22 per cent. in the former, and only 0·074 per cent. in the latter, which may partly account for the difference.

Unfortunately, several of the specimens for mechanical test have had slight flaws on the outside or circumference of the fracture, vitiating the result for strict comparison, yet the elastic limit remains, to enable an estimate to be formed. The general conclusion, as regards the mechanical tests, is, that though possibly aluminium may increase the tensile strength and the elastic limit slightly, yet this is done at the expense of ductility, and in comparison with our usual steel castings—a copy of tests whereof is annexed—I do not find that there is any advantage in its use for increasing the strength and ductility of the metal, but, on the contrary, I think that, in presence of high carbon, it is disadvantageous in this respect. It will be found that neither the elastic limit nor tenacity are in any case more than can be accounted for by the carbon and silicon present; in fact, I have been astonished that they have come out so low.

Some of the carbons are higher than I intended, A 6 and 9, owing to the melter not having allowed for carbon in the alloy; but as all the analyses, as well as the mechanical tests, are given, a general comparison can be made.

I am having another mixture made in the place of A 15, also caused by error of the melter in mixing, as well as one of the same material, but without any aluminium.

The first mixtures, A 1, 2, 3, were cast into castings only, without any mechanical test-pieces being taken.

In A 4 to 9 the steel castings had all been annealed, according to usual practice, before it was thought that unannealed test-pieces, as well as annealed, would have been desirable.

A 10 to 15 had tests made from both unannealed "as cast" and from annealed; the effect of the annealing may be interesting to you.

Enclosed are tables of analyses and mechanical tests, together with analysis of the alloy used.

Explanation.

Chemical analysis: Results are given in per cent.
Mechanical test: *Elastic limit* in tons per square inch.
„ *Maximum strain* in tons per square inch.
„ *Contraction of area* in per cent. of original area of a diameter of 0·757 inches on average.
„ *Elongation* in per cent. measured on a length of 3 inches.

Mechanical test: *Flaw* in per cent. of area of fracture with indication of position.

,, *o.* as on outside or circumference of fracture of test-piece.

,, *i.* in inside of fracture.

Chemical Analysis of Aluminium Alloy

(*June* 14, 1887).

		Per Cent.
Iron		86·69
Carbon combined	1·01	
,, graphite	1·91	
Total		2·92
Silicon		2·40
Manganese		·31
Aluminium		6·50
Copper		1·05
Sulphur		none
Phosphorus		·13

Materials Used.				Chemical Composition, Percentage of						
Mixture.	Swedish Iron.	Spring Scrap.	Alloy.							
Al.	Lbs.	Lbs.	Lbs.	C.	Mn.	Si.	Al.	S.	P.	Cu.
1	56	...	1	·12	traces	·074	·11	·013	·051	...
10	56	...	1	·10	traces	·06	·12	·015	·04	...
13	56	...	1	·15	traces	·093	·12	·013	·037	...
14	56	...	1	·25	·045	·093	·12	·013	·037	...
15	56	...	1	·29	traces	·074	·11	·013	·037	...
4	56	...	2	·15	traces	·084	·19	·013	·038	...
7	56	...	4	·28	traces	·22	·33	·012	·053	...
2	28	28	1	·21	·16	·14	·11	·035	·051	·041
11	28	28	1	·21	·09	·093	·12	·026	·04	...
5	28	28	2	·33	·09	·14	·16	·032	·053	...
8	28	28	4	·49	·16	·23	·31	·023	·049	...
3	...	56	1	·53	·25	·28	·11	·05	·062	...
12	...	56	1	·48	·30	·33	·11	·037	·045	...
6	...	56	2	·65	·25	·28	·18	·036	·054	...
9	...	56	4	·85	·30	·40	·29	·028	·055	...

		C.	Mn.	Si.	Al.	S.	P.
A 1. 56 lbs. Swedish iron.	Analysis:	·12	traces	·074	·11	·013	·051

1 lb. alloy.

Mechanical test not made.
Casting: Fluid; ran sound into small castings.
Remarks: Tough and malleable.

A 2. 28 lbs. Swedish iron.
28 lbs. Spring scrap.
1 lb. alloy.

	C.	Mn.	Si.	Al.	S.	P.	Cu.
Analysis:	·21	·16	·14	·11	·035	·051	·041

Mechanical test not made.
Casting: Fluid; ran into sound small castings.
Remarks: Tough and malleable.

A 3. 56 lbs. Spring scrap.
1 lb. alloy.

	C.	Mn.	Si.	Al.	S.	P.
Analysis:	·53	·25	·28	·11	·05	·062

Mechanical test not made.
Casting: Fluid; casts sound.
Remarks: Hard and comparatively brittle.

A 4. 56 lbs. Swedish iron.
2 lbs. alloy.

	C.	Mn.	Si.	Al.	S.	P.
Analysis:	·15	traces	·084	·19	·013	·038

	Tensile.	Mark.	Elast. L.	Max. S.	Contr. °/.	Elong. °/.
Mechanical test:	Annealed	1159	10·9	21·8	37·17	27
	...	1160	9·5	21·16	41·97	27

Fracture: 1159 Grey, fibrous.
1160 Grey, crystalline, 12 per cent. of area of fracture shows slag mixed with the steel.
Casting: Fluid.
Remarks: Castings are sound and tough.

A 5. 28 lbs. Swedish iron.
28 lbs. Spring scrap.
2 lbs. alloy.

	C.	Mn.	Si.	Al.	S.	P.
Analysis:	·33	·09	·14	·16	·032	·053

	Tensile.	Mark.	Elast. L.	Max. S.	Contr. °/.	Elong. °/.
Mechanical test:	Annealed	1161	10·41	26·28	43·3	32
	...	1162	10·82	26·08	43·7	29

Fracture: 1161 Dull grey, fibrous.
1162 Do. do.
Casting: Fluid; runs sound.
Remarks: Much more brittle than A 2.

A 6. 56 lbs. Spring scrap.
2 lbs. alloy.

	C.	Mn.	Si.	Al.	S.	P.
Analysis:	·65	·25	·28	·18	·036	·054

	Tensile.	Mark.	Elast. L.	Max. S.	Contr. °/.	Elong. °/.	Flaw
Mechanical test	Annealed	1163	14·38	24·3	4·4	3·5	8-*o.*
		1164	14·38	26·28	9·5	9·0	1-*o.*

Fractures: Both are granular, dull grey, with slight radiating crystalline flaws on outside.
Casting: Fluid; runs sound.
Remarks: Unannealed castings are brittle.

A 7. 56 lbs. Swedish iron.
4 lbs. alloy.

	C.	Mn.	Si.	Al.	S.	P.
Analysis:	·28	traces	·22	·33	·012	·053

	Tensile.	Mark.	Elast. L.	Max. S.	Contr. °/.	Elong. °/.	Flaw °/.
Mechanical test:	Annealed	1165	12.20	25·56	19·95	19·0	10-*o.*
	...	1166	11·31	25·58	19·95	18·5	5-*o.*

Fractures: Both are grey, granular; some flaw on outside, owing to imperfect cohesion, caused by film of gas or slag.
Casting: Fluid; sound.
Remarks: Very brittle, and rotten in unannealed casting.

A 8. 28 lbs. Swedish iron.
28 lbs. Spring scrap.
4 lbs. alloy.

	C.	Mn.	Si.	Al.	S.	P.	
Analysis:	·49	·16	·23	·31	·023	·049	...

	Tensile.	Mark.	Elast. L.	Max. S.	Contr. °/.	Elong. °/.	Flaw °/.
Mechanical test:	Annealed	1167	18·59	32·7	16·9	16	2-*o.*
	...	1163	13·18	32·47	22·28	15·5	2-*o.*

Fractures: Both are grey, granular, and have small flaw on outside.
Casting: Fluid; runs sound.
Remarks: Unannealed casting broke easily, brittle; close-grained fracture.

A 9. 56 lbs. Spring scrap. **Analysis:**

C.	Mn.	Si.	Al.	S.	P.	
·85	·30	·40	·29	·028	·055	...

4 lbs. alloy. **Mechanical test:**

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %	Elong. %	Flaw %
Annealed	1169	15·87	40·67	4·4	4·5	...
...	1170	15·74	21·87	2·6	2·5	10·0

Fractures: 1169 Dull grey, coarse, granular; broke at neck of test piece; no apparent reason.
1170 Grey, granular; small flaw on outside of fracture.
Casting: Ran fluid into sound castings.
Remarks: Annealed castings hard and brittle.

A 10. 56 lbs. Swedish iron. **Analysis:**

C.	Mn.	Si.	Al.	S.	P.
·10	traces	·06	·12	·015	·04

1 lb. alloy. **Mechanical test:**

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %	Elong. %	Flaw %
As cast	1189	11·2	22·81	37·1	25	...
...	1190	11·6	22·81	37·1	29·5	...
Annealed	1201	9·72	20·48	60·1	38	...
...	1202	9·97	21·16	30·35	27	...

Fractures: 1189 Coarse crystalline.
1190 Crystalline.
1201 Grey fibrous.
1202 Crystalline.
Casting: Fluid; ran into sound small castings.
Remarks: Tough and malleable.

A 11. 28 lbs. Swedish iron. **Analysis:**

C.	Mn.	Si.	Al.	S.	P.
·21	·09	·093	·12	·026	·04

28 lbs. Spring scrap.
1 lb. alloy. **Mechanical test:**

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %	Elong. %
As cast	1191	11·9	26·28	14·48	13
	1192	13·39	26·78	14·48	12
Annealed	1203	10·02	24·06	50·39	33·5
...	1204	10·47	23·43	52·14	34

Fractures: 1191 and 1192 crystalline; parts show lack of cohesion, as if from gas film.
1203 and 1204 grey, finely fibrous.
Casting: Fluid; ran into sound small castings.
Remarks: Tough and malleable.

A 12. 56 lbs. Spring scrap. **Analysis:**

C.	Mn.	Si.	Al.	S.	P.
·48	·30	·33	·11	·037	·045

1 lb. alloy. **Mechanical test:**

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %	Elong. %	Flaw %
As cast	1193	...	17·68	1·3	2	...
...	1194	...	18·19	...	1	40–o.
Annealed	1205	14·3	29·6	10·0	9	2–o.
...	1206	14·38	35·7	9·5	8·5	2–o.

Fractures: 1193 Broke at neck of test-piece owing to a flaw; vesicular, crystalline.
1194 Vesicular, crystalline; small flaw on outside.
1205 Granular; small flaw on outside.
1206 Granular; small flaw on outside.
Casting: Fluid; ran into sound castings.
Remarks: Unannealed, comparatively brittle and hard.

A 13. 56 lbs. Swedish iron.* Analysis:

C.	Mn.	Si.	Al.	S.	P.
·15	traces	·093	·12	·013	·037

1 lb. alloy. Mechanical test:

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %.	Elong. %	Flaw %
as cast	1195	12·4	22·8	30·73	26·5	
...	1196	11·9	22·8	37·17	25	
Annealed	1207	9·97	20·44	61·26	38	
...	1208	9·92	20·33	64·66	3	

Fractures: 1195 and 1196 grey, crystalline.
1207 and 1208 grey, fibrous.
Casting: Fluid; ran into sound small castings.
Remarks: Tough and malleable before annealing.

A 14. 56 lbs. Swedish iron.* Analysis:

C.	Mn.	Si.	Al.	S.	P.
·25	·045	·093	·12	·013	·037

1 lb. alloy. Mechanical test:

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %.	Elong. %.	Flaw %
as cast	1197	12·12	22·23	7·84	6·5	
...	1198	12·96	21·94	9·04	6·5	
Annealed	1209	9·39	22·75	52·94	31·0	
...	1210	9·47	22·93	56·14	32·5	2-i.

Fractures: 1197 and 1198, 60 per cent. of area are granular, 40 per cent. coarse granular, but crystalline near outside and of a duller colour, appearing to have a different composition to rest of fracture, and show that a film of gas may have prevented cohesion.
1209 and 1210 fine fibrous, grey.
1210 has a small flaw on inside of fracture.
Casting: Fluid; ran into sound small castings.

A 15. 56 lbs. Swedish iron.* Analysis:

C.	Mn.	Si.	Al.	S.	P.
·29	traces	·074	·11	·013	·037

1 lb. alloy. Mechanical test:

Tensile.	Mark.	Elast. L.	Max. S.	Contr. %.	Elong. %.	Flaw %
as cast	1199	12·3	24·11	10·25	9	
...	1200	9·9	22·81	12·02	7	15-o.
Annealed	1211	9·55	23·62	39·9	34·5	
...	1212	9·35	23·62	47·8	33·0	

Fractures: 1199, 70 per cent. of area is granular, 30 per cent. coarse; crystalline of dull colour.
1200, 70 per cent. of area is granular, 15 per cent. coarse; crystalline of dull colour, with large flaw on outside. The large crystals appear of different composition to rest of fracture, probably because a film of gas prevented cohesion when crystallisation was taking place.
1211, 1212 fine, fibrous, grey.
Casting: Fluid; ran sound into small castings.
Remarks: Hard and brittle when unannealed.

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* Each of these are entirely of Swedish iron; carbon content altered by addition of more or less "hard cemented bar."

As Cast.

Mixture.	Chemical Analysis.			Mechanical Tests.					
A.	Al.	C.	Si.	Mark.	Elastic Limit.	Maximum Strength.	Contraction per Cent.	Elongation per Cent.	Flaw per Cent.
10	·12	·10	·06	1189	11·2	22·81	37·1	25·0	...
,,	,,	,,	,,	1190	11·6	22·81	37·1	29·5	...
13	·12	·15	·093	1195	12·4	22·8	30·73	26·5	...
,,	,,	,,	,,	1196	11·9	22·8	37·17	25·0	...
11	·12	·21	·093	1191	11·9	26·28	14·48	13·0	...
,,	,,	,,	,,	1192	13·39	26·78	14·48	12·0	...
14	·12	·25	·093	1197	12·12	22·23	7·84	6·5	see note
,,	,,	,,	,,	1198	12·96	21·94	9·04	6·5	...
15	·11	·29	·074	1199	12·3	24·11	10·25	9·0	...
,,	,,	,,	,,	1200	9·9	22·81	12·02	7·0	15–*o.*
12	·11	·48	·33	1193	...	17·68	...	...	see note
,,	,,	,,	,,	1194	...	18·19	...	...	40–*o.*
Annealed.									
10	·12	·10	·06	1201	9·72	20·48	60·1	38·0	...
,,	,,	,,	,,	1202	9·97	21·16	30·35	27·0	...
13	·12	·15	·093	1207	9·97	20·44	61·26	38·0	...
,,	,,	,,	,,	1208	9·92	20·33	64·66	38·0	...
11	·12	·21	·093	1203	10·02	24·06	50·39	33·5	...
,,	,,	,,	,,	1204	10·47	23·43	52·14	34·0	...
14	·12	·25	·093	1209	9·39	22·75	52·94	31·0	...
,,	,,	,,	,,	1210	9·47	22·93	56·14	32·5	2–*i.*
15	·11	·29	·074	1211	9·55	23·62	39·9	34·5	...
,,	,,	,,	,,	1212	9·35	23·62	47·8	33·0	...
12	·11	·48	·33	1205	14·3	29·6	10·0	9·0	2–*o.*
,,	,,	,,	,,	1206	14·38	35·7	9·5	8·5	2–*o.*
4	·19	·15	·084	1159	10·9	21·8	37·17	27·0	...
,,	,,	,,	,,	1160	9·5	21·16	41·97	27·0	...
5	·16	·33	·14	1161	10·41	26·28	43·3	32·0	...
,,	,,	,,	,,	1162	10·82	26·08	43·7	29·0	...
6	·18	·65	·23	1163	14·38	24·3	4·4	3·5	8–*o.*
,,	,,	,,	,,	1164	14·38	26·28	9·5	9·0	1–*o.*
7	·33	·28	·22	1165	12·2	25·56	19·95	19·0	10 - *o.*
,,	,,	,,	,,	1166	11·81	25·58	19·95	18·5	5–*o.*
8	·31	·49	·23	1167	13·59	32·7	16·9	16·0	2–*o.*
,,	,,	,,	,,	1168	13·28	32·47	22·28	18·5	2–*o.*
9	·29	·85	·40	1169	15·87	40·67	4·4	4·5	see note
,,	,,	,,	,,	1170	15·74	21·87	2·6	2·5	10–*o.*

o. indicates position of flaw as on *outside* or circumference of test-piece.
i. indicates position of flaw in *inside* of fracture.

RESULTS.

Mark of test	O705	O706	O 707	O708	O709	O710
Size of specimen, inches	·753	·757	·759	·760	·755	·755
Original area, square inches . . .	·4453	·4500	·4524	·4536	·4476	·4476
Fractured area, square inches . . .	·2551	·3318	·2827	·1809	·1734	·1590
Permanent set induced, tons per sq. in. .	17·54	17·36	16·77	16·23	11·47	14·47
Maximum strain, tons per square inch .	27·5	27·2	26·6	27·06	24·9	26·9
Contraction of area, per cent. . . .	42·7	26·2	37·5	60·1	61·2	64·4
Elongation in length of 6", per cent. . .	...	...	23·5	...	...	31
,, ,, 4", ,, . .	25	22	26	30	33	37
Appearance of fracture, silky, per cent. .	100	...	100	100	100	100
,, ,, fibrous, ,, .	...	...	...	...	...	...
,, ,, fine granular, p. ct.	...	100	...	...	...	...
,, ,, crystalline, p. cent.	...	...	...	...	...	...

Remarks.—Test-pieces from castings made of Newburn Mild Steel, and passed under Lloyds' and Board of Trade Survey.

Mark of test	O781	O782	O783	O784	O785	O786
Size of specimen, inches	·763	·762	·763	·764	·765	·764
Original area, square inches . . .	·4572	·4560	·4572	·4584	·4596	·4584
Fractured area, ,, ,, ...	·2083	·2231	·3247	·3247	·3216	·3444
Permanent set induced, tons per square inch	12·21	12·35	15·02	16·36	17·00	16·72
Maximum strain, ,, ,,	23·81	25·84	28·10	28·34	28·40	28·15
Contraction of area, per cent. . . .	54·44	51·07	28·98	29·16	30·02	24·92
Elongation in length of 2", per cent. . .	38	35	22·5	25	21	21
,, ,, 1" ,, ,,	55	50	28	36	26	29
Appearance of fracture, silky, per cent. .	100	100	100	100	100	25
,, ,, fibrous, per cent.	...	...	...		...	...
,, ,, fine granular, p. ct.	...	...	...	...	...	75
,, ,, crystalline, ,, ,,	...	...	...	...	...	...

Remarks.—Test-pieces from castings made by Newburn mild steel, and passed under Lloyds' and Board of Trade Survey.

Mark of test	O2770	O2772	O2773	O2775	O2776	O2780
Size of specimen, inches	·539	·2529	·532	·537	·575	·537
Original area, square inches . . .	·2281	·2197	·2264	·2264	·2596	·2222
Fractured area, square inches . . .	·1963	·1385	·1320	·1194	·1661	·1520
Permanent set induced, tons per square inch	15·65	23·36	21·69	21·69	17·15	20·09
Maximum strain, ,, ,, .	42·07	37·59	37·49	40·42	40·41	52·27
Contraction of area, per cent. . . .	14·02	36·9	41·6	47·2	36·01	31·5
Elongation in length of 2", per cent. . .	24	20	25	24	19	19
Appearance of fracture, silky, per cent. .	...	...	...	...	...	...
,, ,, fibrous, ,, .	...	...	...	...	...	...
,, ,, granular, per cent.	...	...	...	...	...	...
,, ,, crystalline, ,, .	...	...	...	...	...	...

Remarks.—Test-pieces from castings made at Newburn, and passed under Admiralty, &c., Survey.

RESULTS—*continued.*

Mark of test	O2875	O3151	O3152	O3232	O3258	O3256
Size of specimen, inches	·76	·55	·554	·543	·546	·558
Original area, square inches	·4536	·2375	·2410	·2315	·2341	·2448
Fractured area, ,, ,,	·3421	·1963	·1885	·1520	·1885	·1963
Permanent set induced, tons per square inch	19·68	14·84	15·37	23·14	17·16	20·45
Maximum strain, ,, ,,	50·68	44·17	37·06	42·42	43·56	41·5
Contraction of area, per cent.	24·5	17·3	21·7	34·3	19·4	19·8
Elongation in length of 2", per cent.	14	10	22	21·5	16	16
Appearance of fracture, silky, per cent.	...	40	50	100	...	...
,, ,, fibrous, per cent.	...	...	...	...	...	...
,, ,, finely granular, p.ct.	...	60	50	...	...	...
,, ,, crystalline, p. ct.	...	...	...	...	100	100

Remarks.—Test-pieces from castings made at Newburn, and passed under Admiralty, &c., Survey.

Mark of test-piece	O705	O706	O707	O708	O709	O710
Size of test-piece in inches	·753	·757	·759	·760	·755	·755
Original area of test-piece, square inches	·4453	·4500	·4524	·4536	·4476	·4470
Area of fracture, square inches	·2551	·3318	·2827	·1809	·1734	·1590
Elastic limit, tons per square inch	17·54	17·36	16·77	16·23	11·47	14·47
Ultimate strength per square inch	27·5	27·2	26·6	27·06	24·9	26·9
Contraction of area per cent.	42·7	26·2	37·5	60·1	61·2	64·4
Elongation per cent. in 6"	...	...	23·5	...	...	31
Elongation per cent. in 4"	25	22	26	30	33	37
	100	...	100	100	100	100
Fine	...	100	...	...	...	...

Remarks.—Testings from castings made of Newburn mild steel, and passed under Lloyd's and Board of Trade Survey.

Mark of test	O781	O782	O763	O784	O735	O781
Size of specimen, diameter	·763	·762	·763	·764	·765	·766
Original area	·4572	·4560	·4572	·4584	·4596	·458
Fractured area	·2083	·2231	·3247	·3847	·3216	34·45
Permanent set induced, tons per square inch	12·81	12·25	15·02	16·36	17·00	16·78
Maximum strain, ,, ,,	25·81	25·84	28·10	28·34	28·40	28·15
Contraction of area, per cent.	54·44	51·07	28·98	29·16	30·02	24·93
Elongation in length of 2", per cent.	38	35	22·6	25	21	21
,, ,, 1", ,, ,,	55	50	38	36	26	28
Appearance of fracture, silky, per cent.	100	100	100	100	100	25
,, ,, fine granular, pr. ct.	...	...	...	...	...	75

Remarks.—Test-pieces from castings made of Newburn mild steel, and passed under Lloyds' and Board of Trade Survey.

Mr. R. A. HADFIELD: It is with pleasure that I note Professor Arnold's able contribution. As his results may be termed the first-fruits of the working of our metallurgical branch of the Sheffield Technical School, those who have watched its development with much interest feel their views strengthened and confirmed that a systematic study of metallurgy, just as in other directions, is absolutely necessary to keep us abreast of the rapid advance of our competitors abroad.

There are several points upon which I must differ from Professor Arnold, but it is difficult in a brief reply like this to cover the ground he has touched upon, which comprises so many important questions; in fact, there is room for several papers, and I trust that Professor Arnold will see his way to put his views on some of these interesting points before the Institute.

In reply, it seems to me that the experiments quoted principally deal with crucible steel, which process, whatever may be its application to tool steel, is for many reasons much less suitable for the manufacture of steel castings on a large scale. For other processes, whilst in some instances aluminium may be employed advantageously, still, notwithstanding the results quoted by Professor Arnold, I am inclined to believe that its use in the large majority of cases is superfluous. Great stress is laid upon the fact of producing sound steel. Now I believe I shall have with me the majority of steel-founders when saying that this is not so much the difficulty nowadays; it is the manipulation of the steel after its manufacture that is so much more important. For instance, the unsound sample, as shown by Professor Arnold, would naturally be quite useless for castings, and apart from, and without the use of aluminium, no steel-founder would think himself competent, or, if he did, he would not find customers, unless he was able to produce sound steel for his moulds.

Then, apart from the crucible process, all the saving shown by Professor Arnold would not apply. For example, in Siemens steel the addition of aluminium would not offer the incidental gains pointed out, such as the saving in coke, wear and tear of the melting plant, &c.; therefore the question is much more narrowed down.

Then, as to feeding the piping with "settling or shrink heads," that is of necessity a common practice with every steel-founder. There is no reason why the same system should not be applied to the manufacture of ingots, whether large or small.

As to the bearing of my paper upon practical results, I can only say that at our own works the knowledge gained by the series of experiments which I have had the privilege of laying before this Institute from time to time, comprising the effects of manganese, silicon, and aluminium upon iron, has been of great value to my firm, and I venture to hope it has been so to others. That such alloys have been, as far as practicable, carbonless, was one of the express aims in all the experiments. To introduce high carbon, such as Professor Arnold has experimented with, would have been of no service from a steel-founder's point of view. As every steel-founder knows, the difficulty in getting hard steels sound is not great, even without the use of aluminium; in fact, the specimens shown by the photos seem to be below the average of even crucible tool steel. That good steel has been made in Sheffield for the past fifty years, and with the crucible ingot trade, goes without saying.

Referring now to Professor Arnold's different summaries: first, he says that he agrees with me "that no general rise of temperature takes place on adding aluminium." What I said was that no *lowering* of the temperature takes place. I believe this is what he means to convey, and it is now to be hoped that, with the general opinion of practical steel-makers, so largely confirmed by such well-known scientists as Professors Osmond, Ledebur, Roberts-Austen, and others, that the last has been heard of the misleading statements circulated so largely that aluminium lowers the melting-point of iron several hundred degrees. I would specially say that, from some recent experiments with the Le Chatelier pyrometer on molten steel, it is quite possible that the difference between fluid and pasty steel may not mean any great rise or fall in the temperature; therefore the calorific effect of the oxidation of aluminium to Al_2O_3, when added to molten steel, even if only a few degrees, might render the metal more fluid for a short time; but in any case, this must certainly not be ascribed to the lowering of the melting-point.

In reply to summary No. 2, and the point upon which to some extent we seem to differ, viz., as to the action of aluminium being analogous to that of silicon, as pointed out in my paper, I do not for one moment say that they are identical; in fact, it is clearly mentioned that aluminium was found to be the more powerful of the two; but I do say that in any instances cited they produce very similar effects. Let us see where we differ.

Professor Arnold says that aluminium is twenty times as powerful as silicon, or, in other words, that 10 per cent. of aluminium (the amount he used for making the experimental products) is equal to 2·00 per cent. of silicon. If he had made the same experiment with silicon as my paper described at the last Paris meeting of this Institute, I am convinced that he would withdraw such a statement. It is quite beyond the facts known to steel-founders. Whatever may be the best and most suitable amount of silicon to be employed, I have seen plenty of sound castings with 20 per cent. of silicon. Only a short time ago I was told by a large maker of steel castings, that though he had two or three years ago extensively used metallic aluminium and ferro-aluminium, its use was now entirely discontinued; and it should be remembered that whatever method he employed to effect sound castings required him to obtain the same results as to ductility, tensile strength, &c. Facts like these are difficult to be explained away. Mr. James Riley, of the Steel Company of Scotland, in an appendix to a recent paper read before this Institute, in summing up his remarks upon aluminium steel, states: "Whilst there are some advantages in using aluminium, the disadvantages are, that it is not desirable to use it in large castings, the steel being rendered more crystalline; that contraction cracks are more liable to occur with this steel, and also that the results are not so much better as to make it desirable to use the metal in steel intended for rolling, &c."

Whatever may be the advantages of employing aluminium in certain instances, it only again proves the old truth that there may be several ways of accomplishing the same end. This is all I contend for.

I feel convinced that if it were possible to employ the element silicon in its pure state, its effect would still more confirm these views. In my own experiments, I obtained the nearest approximation I could to pure silicon, viz., an alloy containing 20 per cent. silicon and only about 2 per cent. carbon. Such an alloy, say sufficient to give ·20 per cent. silicon, would, I believe, if added to 1 per cent. carbonaceous steel, such as described by the Professor, produce soundness and piping of the ingot. Whether the low manganese such as that mentioned (under ·10 per cent.) would then be sufficient could only be determined by experiment. One of the samples mentioned in my own paper, although containing over 1 per cent. of silicon, and under ·20 per cent. of manganese, forged satisfactorily.

Thirty years ago Sir Henry Bessemer discovered that silicon gave sound fluid steel. He patented the process, the additions being made in small quantities, viz., 1 lb. of silicon (by means of ferro-silicon) to 2000 lbs. of decarbonised iron, and the whole question was fully thrashed out in the admirable paper of Mr. F. Gautier on "Solid Steel Castings," and the discussion that ensued, at the London meeting of the Institute in 1877.

Mr. Thos. Turner, Mason College, Birmingham, in his report to the British Association Committee on the "Influence of Silicon," gave the following results, his experiments being carried out on the most difficult kind of material that can be employed, viz., blown basic steel, which is excessively oxidised, and consequently especially difficult to obtain sound:—"Thirty pounds of decarbonised basic metal poured into a crucible remained perfectly quiet for a few moments, but on solidifying, suddenly boiled up, and, although the crucible was not full originally, 75 per cent. of the metal boiled over. No such action was observed in any mixture to which silicon had been added. An addition of only 0·04 per cent. silicon, and of which 0·02 per cent. remained in the ingot, was sufficient to prevent boiling over on solidification." Therefore, in face of this and of the opinions of both practical and scientific experts who agree with me, I think it is rather a strong assertion to make that the effect of aluminium is twenty times as powerful as that of silicon.

A further striking fact has recently come under my notice in confirmation of the analogous effect of silicon and aluminium. At a recent meeting of the Alloys Research Committee, Professor Roberts-Austen drew my attention to the fact that my claim as to silicon and aluminium producing similar effects when alloyed with other elements was confirmed, first, by the fact that the atomic weight and volume of the two elements are almost identical; and, secondly, by a still more striking confirmation, viz., that he had found that when either of these two elements were alloyed with gold, the same effects were produced. In the cooling curves and other data obtained by means of an ingenious combination of the Le Chatelier pyrometer with a photographic arrangement, and by which absolute accuracy is obtained, the above facts were most clearly brought out. A stronger proof could not be found that silicon and aluminium, when alloyed with other elements, produce analogous effects. The results of the Committee will be published in due course. The consensus of opinion, both from scientists and practical workers, therefore clearly confirms my views. In the former I would specially name Professor Roberts-Austen and M. Osmond, whose opinions are entitled to great weight from their special experience in these scientific investigations. Mr. Keep, of Detroit, U.S.A., has also shown most clearly that silicon and aluminium act almost precisely the same upon white iron by causing the combined carbon to become changed into the graphitic form. The same thing was named in my paper as to the effect of aluminium turning a great part of the combined carbon in spiegeleisen to graphitic carbon.

I believe that Professor Arnold's interesting experiment of blowing pure carbonic oxide through a crucible containing molten steel, by which means he obtained an increase of 35 per cent. on the carbon present, would be duplicated if molten steel containing silicon was substituted. M. Gautier, in his paper on "Solid Steel Castings," read before this Institute in 1877 (*Journal*, i. 1887, p. 40), said, "Silicon decomposes the carbonic oxide; therefore if blowholes are filled with oxide of carbon they will be made to disappear by an addition of silicon, for $Si + 2CO = Si + 2CO = SiO2 + 2CSiO_2 + 2C$. The carbon is deposited and dissolved in the steel, and silica is formed." Substitute aluminium for silicon, and we get $2Al + 3CO = Al_2O3 + 3C$, and it seems to me we have a most convincing proof from Professor Arnold's own experiments of the analogy between the elements.

This similarity of behaviour was the reason that I ventured, whilst quite aware of the technical inaccuracy, to describe the effect of the "*metal*" silicon. I cannot but think that we shall eventually find this confirmed by those able to decide. Silicon has not yet been obtained in a sufficient mass to determine its commercial properties. Some text-books describe it as "a non-metallic substance (*at present*)."

To sum up, *silicon and aluminium* produce soundness; have almost the same atomic weight and volume; have very similar calorific power; deposit carbon in the presence of carbonic oxide; turn combined into graphitic carbon; produce almost precisely the same effect when respectively alloyed with gold, as shown by Professor Roberts-Austen; produce similar effects on carbonless iron, as proved by mechanical tests; have similar fractures, both in the cast and in the forged state; and produce coarse-grained metal.

DIFFERENCES.—Aluminium is more powerful than silicon; how much more, it is at present difficult to determine exactly. Aluminium steel, in its cast state, will carry a somewhat larger percentage of its metal before becoming brittle. Aluminium steel seems less red-short.

Professor Arnold refers to piping and contraction. Steel may contract without piping much. For instance, unsound decarbonised iron is subject to linear contraction, although it does not settle or pipe. On the other hand, cast iron, if poured into an ingot mould, will pipe at the top almost as deeply as sound steel, but its contraction is only half that of the latter.

Finally, it should be borne in mind that Professor Arnold's experiments apply to only one kind of steel, viz., crucible tool steel ingots. For the majority of steel work, I do not think that at present the metal aluminium can compete with the results obtained from cheaper mixtures and methods. Even if aluminium only costs 5s. per lb., and is employed in quantities of one-tenth per cent., to a maker of, say, fifty tons of steel castings per week, an extra cost is involved of £1500 to £2000 per annum; rather a serious item in a steel-founder's bill.

I regret that under the rules of discussion, Professor Arnold will not have an opportunity of here replying further to my remarks. If the points on which we differ can be cleared up, he will find me willing to amend the errors of my ways. As a steel manufacturer, one is taught not to dogmatise, and on several points raised by the Professor, and in my own paper, there is much room for more light.

I should like to draw special attention to Professor Ripper's remarks at the close of Professor Arnold's lecture, with reference to the mechanical worker in conjunction with the metallurgical engineer. The former often designs and sends out patterns which are most difficult to cast successfully in steel. If a little more care was given in adapting the article to the material, very many of the troubles, such as unsound work, wasters, &c., would be avoided.

If members could see some of the patterns that are sent to a steel-founder—patterns that would be difficult to make even in cast iron, where the contraction is only $\frac{1}{8}$ of an inch per foot—he would understand why a steel-founder is not the sweetest-tempered person in the world.

Mr. Dagger contributes some interesting information, but is there not some mistake as to his remarks respecting hardness where he mentions that the sample of 7 per cent. aluminium steel would scratch glass? Probably there was much carbon also present; in that case, would not the hardness be rather due to the latter? The carbonless samples mentioned in my own experiments with 5 per cent. and 9 per cent. aluminium respectively were *exceedingly soft*, and could be easily drilled.

As regards the effect of aluminium upon the magnetic properties of iron, my own results entirely differ from those mentioned by Mr. Dagger. Samples containing up to as high as 5 per cent. and 9 per cent. of aluminium were exceedingly subject to magnetic influence; and ferro-aluminium containing 11 per cent., 14 per cent., and 16 per cent. aluminium, are also decidedly as magnetic. I have again tested and confirmed this since receiving Mr. Dagger's remarks. A small magnet will lift two or three ounces of each of the foregoing percentages of the alloy.

As regards M. Pourcel's remarks, I think that he has overlooked the fact that practically the same results as to soundness are obtained either with metallic aluminium or with ferro-aluminium. My own experiments with alloys of silicon and iron seem clearly to prove that if silicon and aluminium are added, in the former case as silicide of iron or silicide of manganese, and in the latter as ferro-aluminium or aluminium, they act similarly in producing soundness. It seems, therefore, only fair to assume that if such results, obtained with ferro-aluminium, correspond with those obtained with ferro-silicon, then, if a pure silicon addition could be made—that is, the element itself—similar results to an addition of the metal aluminium would follow. As pointed out in my own paper in Paris, it would in every way be an advantage to have this experiment actually made. If any one would furnish me with pure silicon, or say where it can be procured in sufficient quantities, I shall be glad to test and settle this point.

This assumption is further supported from the results obtained by adding 20 per cent. of ferro-silicon, which at present is the nearest approach to an addition of the element itself to carbonless iron.

It seems to me, therefore, that the point as to whether the "addition" or "physic" is made by means of the elements themselves, or their ferro-alloys, is not of such importance theoretically. Practically of course there is an advantage in using less bulk, and of not chilling the molten baths to which they are added, though this latter point is obviated by *molten* ferro-additions.

There are many interesting points raised by M. Pourcel, and it is to be hoped he will put his views more fully before the Institute at some early date.

In reply to Mr. Sample's remarks, it would have been better if he had mentioned the special advantages obtained by Professor Langley. At a recent interview with that gentleman during the Iron and Steel Institute visit to Pittsburgh, I understood that he found difficulty in fixing the precise advantage obtained by the use of aluminium in steel manufacture.

I note Mr. Sample says, that whilst ½ lb. of aluminium has a quietening effect upon steel, if it is "wild" 2 to 3 lbs. per ton would be wanted. Thus even with aluminium as low as 5s. per lb. this would mean an extra cost of 15s. per ton! Besides, there is clearly some reason for these "wild" heats, which are the exception, and not the rule. With proper care, and increased knowledge in the behaviour and treatment of molten steel, such heats will no doubt be eventually avoided. As a proof of this, see the interesting discussion that ensued on the reading of Mr. J. Davis's paper on "The Manufacture of Basic Open-Hearth Steel" before the Cleveland Institution of Engineers in December 1890.

With reference to the records of Mr. Spencer's valuable experiments, I would draw attention to the fact that his general conclusion, as regards the effect of aluminium upon the properties of iron and steel, is that such addition is made at the expense of ductility; in fact, in higher carbon steel he particularly points out that its use is disadvantageous.

ON WELDING BY ELECTRICITY.

By Professor ELIHU THOMSON, Boston, Mass.

The subject of welding by electricity has been so recently and so ably treated by Sir Frederick Bramwell before the Institution of Civil Engineers as to render evidently superfluous the re-statement on this occasion of many facts and considerations which might be appropriately advanced, had they not been so well discussed in his paper already.

The electrical arts grow rapidly in these days—a fact which is strikingly illustrated in the development of electric railways. In welding and metal working by electricity the progress is very rapid, and many facts concerning this new art have not thus far been brought out in any publication. Moreover, it should be noted that many new improvements are not ready for publication, on account of the necessity for reserve, until the inventors shall have secured the protection to be afforded by patents.

The purpose of the present paper is to call attention to some of the more prominent steps in the progress being made in the development of electric welding and metal working, it being understood that even while this present paper is in preparation, advances are taking place in the working out of details. It is not, therefore, intended to have this paper take the character of a complete statement, but rather that it shall be a brief review of some phases of the development of the art.

In this art the foundation experiments were made about four years ago. The author had the pleasure of describing some of their results, particularly relative to electric welding, in a paper written in the latter part of the year 1886. The appearance of that paper aroused a considerable interest in the subject, which has continued from that time, and it is curious to note how it has caused the revival of early attempts to use the electric arc in metal welding or working, sometimes in conjunction with a magnet for displacing the arc and converting it into a blow-pipe of great intensity, the latter being a procedure due, it is believed, to Werdermann, in the early days of the production of electric arcs from dynamo machines.

It is not my present purpose to deal with any of these arc methods of electric metal-work. Their practicability is doubtful. So far as is known to the author, there are no existing instances of the use in practice of the electric arc for welding, though numerous attempts have been made, which have failed from one cause or another.

The operations with which this paper deals are those in which the heating effect of electric currents traversing a solid metal conductor gradually brings the metal to the working temperature. This temperature is, in the case of easily fusible metals, much below a red heat, and is hence unattended with luminous effects, which, however, appear in the case of metals softened or fused with greater difficulty.

In order to distinguish this process, applied to the welding of metals, from the application of the heating effect of an electric arc for like purposes, it has been called the incandescent method of electric welding—a designation which is, in my judgment, misleading, for the reason that lead, tin, zinc, and other metals, fusing far below the temperature of incandescence, are thus welded.

Electric welding occurs between pieces of all metals thus far tried, though the perfection of the joint obtained varies with the metals, and with the conditions under which the work is performed. Many different metals unite each to the other, and in many cases the union is such as to possess a strength or tenacity equal to that of both, or of the weaker of the metals joined. In other cases it is not so strong, owing to wide differences in the physical nature of the metals or alloys, or in their tendencies to surface union. Perhaps the incipient alloying at the joint may affect the strength, according to the nature of the alloys possible to be thus formed.

The pieces to be united in electric welding may be in the form of bars of various cross sections, or in the form of tubes or pipes to be abutted and united, or in the form of plates. It is evident that a pipe is virtually a plate rolled up with its edges joined.

The form of the pieces is of little moment, provided that they permit secure clamping of the passage of the current and manipulation. The surfaces to be united are first brought firmly into contact, the pieces being held in heavy conducting clamps for the purpose of carrying a current into them. The current having been put on, heating of the metal between the clamps takes place to a degree which may be regulated at will, or may be automatically controlled. The pressing of the surfaces together unites them, if the joint be a butt joint, while a lateral or transverse pressure, such as that of hammer-hammering or pressing in dies, is used to make a lap-joint. The hammering or pressing is also useful with joints in iron or steel when butt-welding is done, particularly where great strength is required, and the original section at the joint is to be preserved. Such hammering or pressure may be applied simultaneously with the progress of the welding operation, or immediately thereafter, while the metal is still hot.

It is proper here to correct an impression which has gained some currency, namely, that it is the extra resistance caused by the break, or limited contact, between the meeting portions of metal which gives rise to the heating in electric welding. While this limitation of contact surface undoubtedly hastens the heating at the joint, it is nevertheless a fact that a solid bar, joining the clamps of an electric welding machine, will be heated between those clamps to welding temperature, and may be upset by the approach of the clamps one towards the other. Indeed, this process is actually employed to upset collars on shafts, or to set or fasten in place, by a sort of riveting action, collars which have been placed as rings, more or less closely fitting, upon a bar or shaft. The real cause of the concentration of the heating effect at the joint or between the clamps is the relatively greater conductivity of other portions of the welding circuit, which circuit is usually composed of massive copper conductors, kept cool, in the case of large work, by circulation of water. By thus keeping the clamps cool, as well as the conductor in which the welding currents are generated, their conductivity is preserved from running down, and there follows a greater accentuation of heating effect at the joint, with the added result of a considerable saving in the electrical energy required to do the work. In the larger work it has also been found that hydraulic pressure may be advantageously employed, both for clamping and making contact with the pieces to be welded or worked, and for pressing the pieces together in forming the joint. The pressure can be regulated in this case by a pressure governor to a constant amount for a piece of given size. A scale of pressures corresponding to certain sections and materials can be made beforehand, after which the operation may proceed without skill or knowledge on the part of the workman, whose duty is then confined to replacing pieces in the clamps and turning on the current of pre-determined force.

It is not the purpose of this paper to deal to any considerable extent with the technical details of the construction of apparatus, because there is not time for such a discussion, and because these arrangements are subject to wide modification, in accordance with the nature, size, and other conditions of the work. In the practice of electric welding, the conditions of holding in the clamps, the pressure of the pieces together, and the volume of current required, can be determined at the outset, so that a given piece of work can be repeated without variation of result. The operation is therefore capable of being made automatic. The present tendency in the construction of electric welding machinery is towards having its action in most respects automatic, so as to leave little to the skill or dexterity of the operator in charge.

The apparatus first used by the author consisted of an alternating current dynamo, feeding a comparatively high potential current to the primary coil of an induction coil or transformer, the secondary of which was made so large in section, and so short in length, as to supply to the work currents not exceeding two or three volts, and of very large volume or rate of flow. The welding clamps were attached to the secondary terminals. This first type of apparatus has survived to the present day, and most of the apparatus is constructed on that principle, the secondary coil usually consisting of a single turn only. Other forms of apparatus, such as dynamos constructed to yield alternating currents direct from the armature to the welding clamps, are used to a limited extent. While currents of one direction are quite suitable for electric welding, no special apparatus has been constructed for using them. Currents from storage batteries are quite suitable for the purpose, but the batteries should be constructed to stand very great rapidity of discharge, otherwise they become very cumbersome and difficult of application.

The practical results are not very different, whether continuous currents or alternating currents are used, though it is to be noticed that in the discussion of Sir Frederick Bramwell's paper the actions of the two classes of currents were spoken of theoretically, to some extent, as different. It has been shown that in conductors of large section the tendency of alternating currents is to keep to the surface of the conductor, or to flow in the part of it farthest away from its centre. This is undoubtedly true as a tendency, but how far this tendency will be allowed to develop itself will depend on the drop of potential in a given length of conductor, a circumstance which appears to have been overlooked in many of the discussions of this interesting question. In other words, if the fall of potential, as in welding, is, say, two volts in two inches of length of the bar welded or worked, the density of current will be great, even in the centre of the section of the bar, but of course much greater near the exterior. But the heating effect also requires to be greater near the exterior on account of radiation taking place at the outside surface. The practical result may easily be that there is really a uniform heating effect throughout the section of the bar; and without doubt the conditions could be selected to secure such a result.

In welding the ends of two bars, however, they are frequently rounded, and at the start meet only in the centre. In such cases, whether the current be alternating or continuous, the heating effect begins at the centre. A curious fact may here be mentioned. It is found that the distribution of the alternating current may easily be controlled by increase or decrease of self-induction at various parts of the section of the bar by the proximity of magnetisable iron masses. This principle has been applied in a variety of ways to govern the distribution of the heating effect, and also to effect the restriction of current to the weld in thick rings. This will be adverted to later.

A glance at some of the typical actions and conditions found to exist in the welding of different metals may not be out of place.

With metals such as lead, tin, and zinc, the degree of heat required does not, of course, produce light, and the progress of the heating cannot be watched by the eye, as in the case of iron or steel. Therefore the plasticity, softening, or fusion, is really the index of the heat which the abutted ends have acquired. If the precaution be taken to shape properly the meeting ends of the sections before applying current and pressure, the joining of lead pipe sections, end to end, can easily be accomplished electrically, and the joints are very good and sound. The welding occurs best by an actual fusion of metal, a sort of autogenous soldering, or soldering of lead with lead. The meeting edges are best made bevelled or tapered so as to expose a smaller section than that of the pipe or bar to the melting action of the current. On account of the poor conductivity, for heat and electricity, of lead and its alloys, comparatively large sections may be worked by moderate current strength as compared with copper.

The metal tin welds electrically with ease, as does also zinc, and even such brittle metals as antimony and bismuth present no difficulties. The welding of aluminium requires special precautions, but can readily be accomplished, and the joints, when properly made, are exceptionally strong and tough. In this case, recourse is generally had to the automatic welder, in which machine the conditions prior to putting on the current can be very accurately set. In fact, while by hand-work a considerable proportion of failures will occur in aluminium welding, by the automatic machine good joints may be made in regular succession. Even magnesium, oxidisable as it is, is readily welded because it melts before reaching the temperature at which it takes fire. In the welding of brass to brass, the conditions for the most successful work vary somewhat with the nature and composition of the alloy; and here it may be remarked that a much greater current strength is required than in the case of iron of equal section, although the specific electric resistance of cold iron is nearly the same as that of brass, and the latter metal is much more fusible. This requisite of larger current for brass is due to the fact that with brass and similar alloys, such as German silver, only a comparatively small increase of resistance takes place with the increase in temperature, while with iron the resistance at the welding-heat is a number of times as great as that of the cold metal.*

The temperature resistance co-efficient is, in general, much higher in the case of simple metals than in metallic alloys. The conductivity for heat has also a decided influence on the heating, and the comparatively low heat conduction of iron assists the work materially. Brass of ordinary composition scarcely seems to become plastic at all before melting. Hence the joints made with it generally show, in part, a real fusion, and not merely a softening. In cases where the pressure used is too great, the joint is obtained by the crushing up of the hot metal in a semigranular state before fusion, but this joint is not generally so perfect as the other. Some of the bronzes, and notably the alloy called aluminium bronze, show some plasticity before fusion.

The behaviour of copper in welding by the electric current may be noted. It is an example of a metal of very high conductivity for heat and for current. Naturally, to weld it electrically, the current strength required will be much greater for a given section than for metals of smaller conductivity. The heat produced escapes rapidly by conduction, and the low resistance of the metal requires a great current to be passed to cause it to heat. This is compensated for, in large part, by the fact that the copper requires a very low potential, or E. M. F.—less than a volt across the joint. The rate of energy-consumption being the product of the current used by its electro-motive force, and the total energy consumed being the product of this by the time, it will be seen that if a copper weld be made, in a short time the losses by conduction and radiation from the joint can be kept down to a moderate percentage of the total energy. Copper, as is well known, becomes decidedly softened before melting, and is, therefore, often forged hot. Hence, joints may be made apparently without real fusion; or, in other cases, when a lighter pressure for forcing the pieces together is used, a real fusion of portions of the meeting ends may occur. While in the electrical welding process joints are obtainable with most metals without the use of any flux, it is not the less true that a flux is sometimes desirable for good work, particularly with those metals the oxides of which do not melt at the temperature of welding or union of the pieces. Thus a flux should be used with brass, which has a temperature of welding and union below that of the fusing-points of oxide of zinc or of copper, while a flux is not an essential in the welding of copper, the melting-point of which is above that of its oxide. In like manner, a temperature which will melt the oxide of iron on the surface of a bar is below that of the welding of soft iron, while such a temperature would ruin tool-steel. The latter requires, therefore, a flux to be used with it, melting at a safe temperature and dissolving the scale. The covering action of a flux is also useful in most cases to prevent oxidation. A peculiarity of the electric welding process, and one which renders it capable of forming joints, even where metals may be coated with oxides infusible at the temperature of fusion of the metals themselves, is the expulsive power exerted to remove metal sidewise from the joint, and thus bring unoxidised, clean surfaces into contact at fusing temperatures. It is this fact which more than any other accounts for the universal applicability of the process to metals and alloys. For example, the chief obstacle to the soldering or welding of aluminium may be the skin of alumina formed on its surface when hot, which not only protects the metal from further oxidation, but prevents its union with other pieces of metal. The alumina is only fusible at the highest temperatures, whereas the metal fuses at about a red heat. Let two pieces, however, be vigorously pushed together while softening at the joint; then the oxidised surfaces will be thrust aside outwardly from the joint, and the new metal of the interior of the pieces will come together in the cleanest possible state, and unite. The removal of the burr or excluded metal of the joint can be afterwards effected with proper tools.

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* Reference is made to the curve in Sir F. Bramwell's paper in connection with which the effect of increase of resistance by temperature in assisting the work is very thoroughly and ably discussed.

The uniting of iron and various grades of steel is, of course, the most important industrial use of any welding process, and this is particularly true of an electrical one. The behaviour of soft iron is particularly favourable to the welding operation. Its great plasticity before fusion renders its working and welding easy and simple. In the case of steel, for the higher grades of which, especially the ordinary blacksmithing operation is liable to be very uncertain, the electric process is rendered easy and certain for all grades. When it is remembered that the exact conditions of current, conduction, and pressure at the joint may be made definite, and are perfectly under control, it is seen at once that, if the pieces are weldable at all, we can even establish an automatic control of the welding after these conditions have been once determined.

Electric welding machinery is now constructed in which these features are incorporated, and which is, at the same time, provided with appliances for shaping or hammering the joint, so as to preserve the diameter and increase the toughness of the metal thereat. Where the heat of the welding tends to change the structure or cause a tendency to granulate, hammering may be applied to retain the structure, or to renew it during or after the union of the metal process.

There are many kinds of work to which electric welding seems to be peculiarly applicable. It is now in use largely for the joining of sections of wire into one length, and its use for such a purpose is still extending. Joints are regularly made in wires, which are afterwards reduced in diameter by the wire-drawing process, various metals, such as copper, iron, brass, &c., being treated in this way. In other cases the electric welding process replaces the twisted joint formerly made in galvanised telegraph and similar wires—the galvanising operation either preceding or succeeding the making of such joints. Even the ends of wire cables are readily jointed, the resulting weld possessing a strength not much inferior to the cable itself, and probably about equal to that of any heated or annealed portion. The making of such joints requires, of course, special precautions, but the operation is quite simple otherwise. In the welding and coiling of pipe the electric method seems to be especially expeditious and useful. Coils of pipe are now made continuously, as section after section of pipe is welded on. There is no limitation to the length of pipe which may be welded and wound as one coil.

There is neither time nor space to go into full descriptions of the details of each operation. The author must limit this paper to brief statements of what has been done in the development of this field of work. The process seems destined to work a revolution in pipe-coiling operations. A machine will soon be tested which is intended for welding sections of six-inch extra-heavy pipe together endwise. The current developed in this machine may reach 70,000 amperes, though its normal work will demand somewhat less than this. Most of the details of this and the other welding apparatus thus far constructed and put to use have been devised and arranged by Mr. Hermann Lemp, to whom the greatest credit is due for the original character and effectiveness of the machinery itself. Lieutenant W. B. Wood has also had in charge a number of special pieces of work in adapting the welding process to several important applications.

Somewhat akin to pipe-welding is the making of armour-piercing shells (as devised by Mr. Wood) from sections of varied grades of steel and without screw joints. The sections are made separately, such as a head or point of high-grade steel, a tubular middle section of softer, and a soft back-piece perforated for loading; or the shell may be made of two sections only, jointed near the middle. These sections are placed in a welding apparatus of special and most interesting design, where they are welded together to complete the shell body, which is afterwards finished outside. Experiments in firing shells made in this way have given satisfactory results, and further developments are being made as rapidly as possible. This, with much other work of like nature, is in the care of Lieutenant Wood. In the making of rings, links, bands, &c., the electric welding operation is particularly useful, and a number of machines specially designed for such work have been put into practical operation. Even rings of small diameter relatively to the weight of section of stock used are made with facility, though at first it might be thought that the current would pass around the joint and through the solid metal of the ring, instead of the joint or cut ends pressed together. This is true in part; but the actual result is that only in very stout rings is there much heating outside of the joint, and then only enough to make the ring flexible, so that the ends of metal at the joint may be readily moved together. With the alternating currents used in electric welding, not only does the current take the path of least resistance in largest amount, but it also seeks the short path, or path of least counter-induction or self-induction, and therefore will not go round a ring as freely, other things being equal, as along a short, straight path through the joint at one side. Furthermore, if it be desired to check any flow around the ring still more effectively, we have only to introduce into the centre of the ring or link a magnetisable core of iron, which effects a great increase of the counter-induction mentioned.

An important matter which may be mentioned in this connection is the facility with which the milder grades of steel may be manipulated in the welding by electricity. The advantage of the superior strength of steel over puddled iron may thus be secured, which allows the use of a cheaper material, and less of it for a given strength. This remark applies forcibly to chain-making, in which the substitution of low steels for iron secures the double advantage mentioned, with the other advantages of the electric process over the ordinary ways of working. Considerable attention has therefore been given to the development of machinery for chain-work, and a small working apparatus has even been made, which takes a wire from a reel and turns out lengths of chain with electrically welded links, the operation being automatic throughout. A curious feature of electric welding-work is that two or more welds may be simultaneously made in parallel. This fact is utilised in chain-making, where two welds, one at each side of a link, are made simultaneously. There are not yet in industrial operation any chain machines using the electric process. This step, however, is reserved for the near future. A special heavy chain machine will soon be completed.

Thus far the field of work in the manufacture of tools and parts of machines by welding different forms and different qualities of metal together has been but slightly explored, and principally in an experimental way; but it is believed that eventually electric welding will find a large application in such directions.

The size of work which can be done by the electric method is limited only by the size of apparatus and the power to generate current for it. Unquestionably there are natural limits to its applicability and economy, which remain to be determined. It is not to be supposed that this process can or will supplant entirely the other methods of welding, any more than electric lighting supplants gas, oil, or candle light entirely. That it already has enlarged, and will continue to enlarge, the field of mechanical possibility cannot be doubted, in view of the very considerable developments which have taken place in the past two or three years, embracing only the infancy of the art.

In the comparisons between the strengths of electrically welded stock and the results of ordinary welding by the blacksmith, given in Sir F. Bramwell's paper, referred to above, the electric process has shown a somewhat higher percentage of strength, notwithstanding the fact that in making up the averages, the specimens which broke outside the weld were, in the tests, counted out, and only those which broke in the weld were taken. If the specimens which broke elsewhere than in the weld are counted at 100 per cent. strength, the actual average strength obtained is between 95 and 100 per cent. In similar comparisons as to bending, it was found that the electric welds would not stand bending as well as the others, but when it was remembered that the electric welds were butt-welds, and that in making them a comparatively very short section of the metal at each side of the joint was heated and annealed, while the ordinary welds were lap-welds and involved the heating and softening of a considerable length of the bar, it was seen that the bending in the former case through a given angle will virtually be more than in the other case, where more of the length takes part in the flexure. In such comparisons, as afterward pointed out by Sir F. Bramwell himself, each specimen should be softened by heat to an equal length, and afterward bent under like conditions; otherwise no conclusions can be drawn from bending tests.

It will readily be understood that the heating effect of very heavy electric currents may be applied to other cases of metal-working than welding. Thus, it may be used to heat pieces for soldering or brazing, an operation which only differs from welding in the use of a more fusible metal between the surfaces to be united. In many cases the advantages of control of temperature, quickness of heating, and convenience of holding the pieces will be found greatly in favour of the electric method. In fact, an electric brazing machine has been regularly in use for some time past for bicycle construction, while in other instances such welding takes the place of joints formerly made by brazing with the blowpipe. The application of the electric methods to many tinplate soldering operations is likely to become industrially, as it has been already experimentally, successful.

Again, the use of electric currents of large volume and low potential for locally heating metal to plasticity for shaping, swaging, rolling, spinning, or otherwise giving form to it, seems destined to be applied on a large scale in the future. The author has found it easy to apply the heating currents to metal pieces and to give them rotation or other movement in shaping. As an example may be mentioned the heating of portions of zones of pipe and the revolutions of the pipe itself, or of the tools around it, to raise locally beads or expansions, or form constrictions or depressions, to close or expand the end of the pipe, to cut it off, to spin it into various forms, such as hollow shells or vessels; in fact, to deal with it without cutting tools, at the same time that its temperature may be kept up to plasticity by the electric current. The end of a pipe may be heated, rolled to contract or expand it, and a thread rolled on it, either internally or externally, if desired, at the same time. These operations may be performed while the work is surrounded by hydrocarbon gas or vapour, which prevents scaling of the surfaces. Trials of work of this kind point to future applications in various ways.

Among the operations which can be readily performed electrically is that of heating a rivet in place by current passed through it and heading it while hot. In numerous trials, it has been proved that short, straight sections may be used as rivets, and both heads formed simultaneously, either as projecting heads or as countersunk heads. The heating action may be so quick as actually to heat the rivet without communicating heat to the plates; or it may be slower, and the plates themselves may partake, in part, of the welding action, so that the rivet welds to the plates. Naturally the current for this work is large, but the potential required is low. The degree of applicability of the process in practice will, it appears, depend on the conditions and requirements in each case. The operation is evidently only a modified upsetting process, in which the section of metal between the clamps or current conveying blocks is heated. It is, of course, not essential to this operation that the whole length of the rivet be heated, or that both heads be formed at the same time. In fact, the projecting end of a rivet may receive contact from the heading block as one terminal of the circuit, and the return or opposite terminal may be the plates to be riveted, and this would be the preferable arrangement where the rivet body was long and the plates to be riveted together were thick. The author has, in addition, devised new riveting operations specially adaptable to the electric process.

Before closing this brief review of some of the phases of electric metal-work, reference may be had to the subject of economy in the work done, and to the power required. In the first place, the conditions vary so greatly that no general statement can be made; but when it is remembered that, for making steam, waste gases from operations requiring high temperatures are still hot enough, and that the nature of the electric current enables high temperatures to be secured from power developed from steam at comparatively low temperatures, it is easily seen that in many cases of heavy metal working, power for welding is already at hand, just as power for hammering in heavy forging is obtained, in many cases, from the waste gases of forges. Again, by the electric process the large water powers can be turned to account in metal-working, and places where fuel is dear and water power plentiful may, in future, take positions of importance with respect to certain varieties of such work.

Furthermore, where steam is generated for the express purpose of welding and working metals by electricity, the localisation of the heat to the exact point required, as compared with heating a considerable length or mass in the fire, with the loss of heat involved in so doing, may set-off the heavy losses in the generation of power from steam. It is readily seen that the economy of heating to high temperatures in the fire must fall as the temperature of the metal rises, the temperature-difference between that which gives heat and that which receives it becoming less and less. In the electric process the reverse is true, aside from increased loss by radiation and conduction as the temperature rises. During heating, the increasing temperature of the metal in most cases adds greatly to its resistance, and this in turn increases the electrical economy of the plant, or increases the proportion of the electric energy converted into heat in the work itself.

Considered in relation to automatic character, range of adaptability, the convenience and cleanly nature of the work, the perfect control of temperature secured, and the uniformity of result, the electric welding and metal-working processes are decided advances over the prior art, and seem destined to a wide application. Already they have given rise to new methods of construction and have produced new articles of manufacture, and they will doubtless advance continually in this respect, in addition to their application to old constructions, or to the replacing of old processes in established manufactures.

Lack of time and pressure of other work have prevented the author from presenting more than a sketch of the developments of electricity in metal-working, and a consideration of many interesting details has been necessarily omitted.

The paper was illustrated by a number of photographs of electric-welding machines, adapted to special processes, and by the actual operations of one of the electric-welding machines in ordinary use. Copies of the former have been promised to the Institute by Professor Thomson, but they had not come to hand in time to be reproduced in this volume.

DISCUSSION ON PROFESSOR THOMSON'S PAPER.

Mr. **Ewing Matheson** (Leeds) said that he had spent some little time in London in investigating the machines which Professor Thomson had sent over, and one needed but little time to be convinced that the electric process was practical, as they had seen it there. What interested manufacturing engineers was the facility afforded for mechanical operations which they had every day in their factories. Unfortunately, in one respect the machines which came to London were experimental machines, intended only for exhibition purposes, and the clamps and subsidiary parts were not devised for any particular branch of work. On his arrival in America a week ago, he went over to Boston and spent some days at the factory there, to which Professor Thomson had invited the members of the Institute for the purpose of seeing, not the mere practicability of electric welding, because they had seen that before, but rather to see the means for adapting the machines to particular branches of trade. He was very much struck while there with the peculiar appliances for the different shapes of work wanted in their every-day operations. Just as, in a lathe or planing-machine, it was not the time taken in the actual cutting, but the time taken in putting the pieces in and out, so, in the welding machine, some remarkably ingenious devices had been made, by which, by an almost automatic operation, pieces of various shapes could be inserted in the machine, welded, and taken out again, in a marvellously short time; and not only plain butt-welding, which they had seen there, but also lap-welding. T-pieces and other shapes were put in the machine, the machines being furnished with clamps for that particular purpose. Perhaps the most ingenious of all the machines was the one for welding the hollow shells which Professor Thomson had shown them. The soft steel tube and the hardened steel point were put together, not only quickly, but systematically; that is to say, the concentricity of the two was maintained. He did not know whether there were any American gentlemen present who were using the machines, but it seemed to him that it would be very interesting to the Institute if they could hear a little of their actual application commercially to trade purposes. In England he believed there was but one works where they were working them every day in the smithy, but no doubt when they got back again others would be in use. He would strongly advise gentlemen who were interested in the matter to go to Boston, if they could, and see what he himself had seen there.

Mr. P. C. **Gilchrist** thought, from the very clear statement that they had had, that it was quite evident that the difficulty in welding almost every metal had been completely conquered, more especially the difficulty of welding different kinds of steel. There were one or two uses to which steel was not yet put as much as it ought to be, notably that of chains, and if the cost of making the welds in chains was right, there was no doubt that such a method of welding would lead to a very great increase in the consumption of steel for purposes such as chain-making. While it was against their rules to ask the cost, it was not against their rules to ask for pretty nearly the same thing, so that if the author of the paper could give them the actual horse-power required for making up so many hundred-weights of chains of particular sizes, they could determine the cost. Its use would depend entirely upon that. There was no doubt, after the very clear statement that they had had that day, that the welding could be done, and that every metal, steel included, could be thus welded. Whether electricity as a mode of welding was going to be used largely or not, would depend entirely upon what it was going to cost; and if the author could tell them the amount of horse-power required to produce certain specific work, he thought that then they could form a very fair idea whether it would pay them to apply it to their works or not. As he represented one out of a good many members who knew nothing whatever about the subject before, he ventured to tender on their behalf, as well as on his own, their very best thanks for one of the clearest expositions on the subject he thought that they had ever heard.

The **President**, in proposing a vote of thanks to Professor Thomson for his very excellent paper, said that they were probably aware that Professor Thomson was a distinguished inventor and discoverer through his electric researches; and amongst the great manufacturing establishments of the United States were the works of the Thomson-Houston Company, of which he was the inspiring genius. For his own part, he thought it would be a misfortune to leave the United States without seeing those stupendous works, and the wonderful applications which they had made in electrical power. He himself could see, as a practical man, that there were many applications of that electrical welding. For engineering purposes, he could see that the power of welding up finished work at a bench, under the direction of a fitter, without the waste of heating in a smith's fire, would permit of the use of new forms of metals, and of new applications of steel, in the construction of engines and machinery of all descriptions. They were only at the beginning of the developments of this process. They were very grateful to Professor Thomson, not only for submitting his paper, but for showing them in a practical manner the methods and the machinery which he adopted. The Professor had taken considerable time, pains, and trouble to show the members those applications of electrical welding. He asked for a vote of thanks by acclamation to Professor Thomson for the paper which he had given them that morning.

The vote having been given, Professor **Thomson**, in reply, said it gave him great pleasure to have had the opportunity of bringing the matter before the attention of the Iron and Steel Institute. He might answer the inquiries made in relation to the power taken by saying, that, of course, the actual horse-power consumed varied greatly—that was, it depended upon whether they made the weld quickly, or whether it was made slowly. That fact would govern the actual horse-power which had to be at command. Of course, the time element came in in the one case to abridge the amount of energy consumed. He could simply refer to Sir Frederick Bramwell's paper for matters of that kind, as he considered that the information and figures that Sir Frederick gave were quite accurate and well up to date; and at the same time Sir Frederick called attention to other interesting matters, and one in particular that he might refer to, where Sir

Frederick had instituted comparisons between electric welding and blacksmith welding. There they would find that the actual fuel consumed in each case during the operation was about the same, although the electric welding was heated twice—that was, the hammering was not finished during the first heat. If the hammering had been finished by automatic means during the first heat, the consumption of fuel would have been less in the electric welding.

The following paper was then read:—

THE WEAR OF METAL AS INFLUENCED BY ITS CHEMICAL AND PHYSICAL PROPERTIES.

By C. B. DUDLEY, Ph.D.,
Chemist of the Pennsylvania Railroad, Altoona, Pa.

In October 1878, and again in February 1881, I had the honour to make public, through the medium of the American Institute of Mining Engineers, the results of an extended study of steel rails which had been in service, and which were taken for the purpose from the tracks of the Pennsylvania Railroad Company. These studies appeared in three papers. In the first of these papers the question of what kind of steel is least liable to fracture or disintegration in the track was the principal one considered. In the second paper the question discussed was, Does the power of steel to resist wear increase with the hardness? In the third paper the relation between wear and the chemical and physical properties of the metal was the principal point considered. The general results arrived at, or the conclusions reached, were as follows: 1. That a mild steel is less liable to fracture, and, if properly made, less liable to crushing or disintegration in the track than a harder steel; 2. That the wearing power of steel in rails not only does not increase as hardness increases, but, on the contrary, diminishes; or, in other words, that a mild steel gives less loss of metal under the same service than a hard steel. These conclusions may be briefly stated in a single sentence—namely, in rails mild steel is not only less liable to fracture and disintegration in the track, but it also gives longer life, or wears more slowly under the same traffic, than harder steel. It is perhaps hardly necessary to add that by mild steel is meant steel with smaller percentages of carbon, phosphorus, silicon, and manganese than is characteristic of harder steel.

My own criticism of this work, after the lapse of ten years, and after all the discussion which followed the publication of the papers above mentioned, may perhaps be fairly summed up in four conclusions:—

1. If I had the work to do again, I would certainly determine the sulphur in the rails, since all our studies during the past ten years on the influence of sulphur point strongly in the direction of indicating that the sulphur has an important influence on steel, especially in its effect on the carbon.

2. The influence of silicon, and especially its influence from the metallurgical standpoint, seems to be much better understood now than at the time when these studies were begun; and if an ideal formula, representing our views as to the best possible composition for steel rails, were to be made at the present time, the silicon limit would be raised somewhat, possibly to the favourite figure of Mr. Sandberg—namely, 0·10 per cent.

3. It is possible that, in the first paper published, the influence of the chemical composition on what is commonly known as crushing or disintegration of rails in the track was made more prominent than the facts would warrant. More mature or riper studies would seem to indicate that disintegration or crushing of steel is largely a resultant of lack of soundness in the ingot, and is more mechanical than chemical, except in so far as chemistry may be responsible for the soundness of the ingot. However, upon this point of sound ingots, we have seen little reason to modify the views held for some time, that time is more important in securing sound ingots, especially time in certain critical parts of the process, than any other single element. If our views are correct, sound ingots, with consequently sound rails, can be made from steel of varying composition, provided time is allowed at the right points in the process, and the claim that high manganese and high carbon are essential to secure sound ingots is, in our judgment, not well founded, provided that time enough is allowed to make the steel properly.

4. In all our later studies on the wear of metal, we have, as far as possible, avoided a method of deciding which metal is best that attempts to give what may be called absolute results. In other words, loss of metal by wear per million tons has some necessary errors in it, and accordingly, in our later studies, we have adopted this method of comparison:—Two metals of

different composition are subjected as nearly as possible to the same wear, and the one which wears the faster, by comparison with the other, is regarded as the poorer, as will be explained a little later. It would, perhaps, have been difficult to use this method on rails selected from different portions of the track, the extremes being somewhere about 100 miles apart; but if we had the work to do again, a strenuous effort would be made to use the method of comparison. Of course, this is possible where direct positive experiments are made.

One point further in regard to the work already done on this subject. Samples of all the rails which were discussed in the third paper above mentioned have been carefully preserved, with the idea in mind of some time repeating the work, with the improved means and methods which time and study in the realm of chemical metallurgy should place in our hands. Especially has it been hoped that some methods of chemical analysis would be devised which would enable us to determine, not only the total amount of carbon, phosphorus, silicon, manganese, sulphur, &c., in these various steels, but also how these substances were combined. For example, does the phosphorus in any given rail exist as phosphide, or partly as phosphate, or both? Is the silicon simply alloyed, or chemically combined with the iron? Does the carbon all appear as strength carbon, or is some of it graphitic, or combined with the iron in such a way as to form a crystalline body which adds nothing to the strength? The past ten years have done something in unravelling these mysteries, but hardly enough, we think, has been developed as yet to enable us wisely to re-examine these rails. It has been our belief for some time that no decided step forward in the chemical metallurgy of steel could be taken until we have solved some of the questions as to how the various impurities which occur in steel exist in the metal; and we may add, that it is not from lack of interest in the subject, but from necessary devotion to study in other lines, that our own work in this field, and our possible contributions to knowledge on this subject, have been so small.

Otherwise than as regards the criticisms above mentioned—namely, that the sulphur should have been determined, possibly the silicon limit raised a little, the influence of the method of manufacture on the final product made a little more prominent, and the comparative method used as far as possible in determining the difference between good and poor rails—we have seen little occasion to modify the conclusions stated in the papers as published; that is to say, during ten years past, with our minds constantly directed to the question of what kind of steel will give the greatest safety and the least wear, not only in rails, but also in almost all constructive uses, we have seen no occasion to change the main conclusion previously reached—namely, that mild steel is not only safer for rails and for other constructive purposes, but also that mild steel gives better wear, or loses less metal under the same traffic, than harder steel. It seems quite probable that this conclusion will hardly be accepted by the mass of engineers, or by those who are engaged in metallurgical industry, and the object of this paper is simply to bring up to date additional information which has been accumulated on this subject during the past ten years. It is perhaps unfortunate that a larger number of direct experiments have not been made during that time; but progress in such a study as this must necessarily be slow, and methods of making experiments which will give unquestioned results do not always readily present themselves, so that perhaps in some respects the delay has not been so great a misfortune. We are much better prepared to-day to make positive experiments than ever we were before, and we have experiments already started which we hope will throw much light on this subject. We hope we may have the good fortune to bring the results of these experiments to your attention at a later date. Meanwhile, what light have the past ten years thrown on the special subject of the relation between wear and the chemical and physical properties of metal?

1. Since the papers above referred to were published, no systematic study of steel rails has been attempted in the Pennsylvania Railroad Laboratory. A few tons each of rails of different specified composition were obtained and put in the track, with the idea of making a positive experiment on wear. Unfortunately, owing to changes of alignment, and in the *personnel* of those who had charge of the experiments, these rails were lost sight of, and no positive conclusions can now be drawn from them. General observation has, however, been constantly maintained, and an

occasional analysis of a remarkable rail taken from the track has been made, but these have not at all altered the conclusions previously expressed.

2. It will be remembered by those who are familiar with the discussion which followed the publication of the papers on steel rails, that some trial rails, according to the formula suggested in the first paper, were made in Germany, and inspected by Mr. Sandberg, who made his work the subject of a contribution to the discussion. The place where these rails went into service never came to my knowledge until a little over a year ago. At that time I received a letter from Mr. P. H. Conradson, the chemist of the New York and New England Railroad, stating that he had found in the records of that road that 2500 tons of steel rails, in accordance with the formula suggested in the first steel-rail paper above referred to, had been made at Gütehoffnungshütte, Germany, and had been laid on their road. Mr. Conradson's letter gave the formula on which the rails were ordered, which is practically the formula of my first steel-rail paper, and also states that the records show a number of reports of inspection, signed by Mr. Sandberg, with analyses made by Mr. Magnus Troilius. A number of analyses are also given, taken from the tests of inspection, showing, in general, that the rails came within the limits of the specifications—namely, in no case was carbon above 0·35 or below 0·25 per cent.; manganese was in no case above 0·40 or below 0·30 per cent.; phosphorus was between 0·055 and 0·075 per cent., and silicon varied from 0·01 to 0·08 per cent.; most of them being about 0·05 per cent. The physical tests were also fairly close to the assigned limits of the specifications—namely, they were generally within 75,000 pounds tensile strength per square inch, with not less than 20 per cent. elongation, the limits being from 73,000 to about 80,000 pounds tensile strength per square inch, and 17 to 23 per cent. elongation. The rails weighed 60 pounds per yard, and were put in the track where they could be subjected to the severest service. They remained at this point seven years, and were taken up to be replaced with a heavier rail. Upon receipt of Mr. Conradson's letter, the matter was brought forward with the officers of the road, with the idea in mind of obtaining positive figures as to the tonnage which had

passed over the rails during the seven years; but although data on this point was promised, yet, owing to changes in the management, it was never furnished. We are, therefore, without positive data, expressed in figures, as to how these rails wore. The statements, however, of those most familiar with the rails while they were performing their service were to the effect that they were in every sense satisfactory, and that they gave excellent results. The words of the one most competent to judge, quoted by Mr. Conradson, are as follows: "These rails have not changed any during these seven years of continuous use so that it can be detected by the naked eye." It would be gratifying to have positive figures as to the tonnage and loss of metal by wear, but in the absence of such data it is perhaps not too much to say that even if we do not have from it so positive a confirmation of our views as could be desired, there is certainly nothing in the data to controvert the idea that mild steel gives better wear in rails than hard steel.

3. I am aware of the conclusions reached by M. Verschovsky, engineer-in-chief of the Russian State Railways, which were stated in a paper read before the Railway Congress in Paris in 1889. I have not seen the original paper, but simply a translation. Those who have read this paper know that the conclusions reached by M. Verschovsky seem to be directly opposite to the conclusions which we have reached—namely (if we can trust the translation which I have), "the best wearing rails have the greatest tensile strength with the least elongation;" and again, that the "rails which broke were softer, as far as indicated by tensile strength and elongation, and there is a difference between a hard rail and a brittle one." Still further, as regards the chemical composition, "the best rails contain more carbon and manganese than the brittle ones, and in all cases much more silicon and less phosphorus." In the absence of data as to what constituted the best rails—that is, as to how the best rails were decided on—and in the absence of any positive data of loss of metal by wear, it is, of course, exceedingly difficult to criticise or explain the conclusions obtained by M. Verschovsky. However, one point in the paper seems to throw some light on the possibilities of the case. It is stated that, in consequence of the

specifications issued by the Government, the steel-works did all in their power to produce a soft steel, so as to ensure that the "frozen rails should stand the falling or drop test prescribed," and that this result was accomplished; but that, as a concomitant of this soft steel, a new difficulty appeared, which was that after a few months of wear the rails began to crush or flatten at the ends, so that in a short time replacement was found necessary. To our minds this seems to indicate that, as the result of the effort of the steel-works to produce soft steel, very unsound or porous ingots were obtained, which produced rails that were not sound and homogeneous, and which would be likely to behave exactly as M. Verschovsky describes. It will be remembered that this difficulty of getting sound ingots with soft steel was largely the burden of the discussion which followed the publication of the steel-rail papers, and it seems fairly probable that the difficulty which M. Verschovsky describes may be entirely due to this cause. If the steel-works, in trying to make the soft steel, so hurried the process that unsound and porous ingots were obtained, we see no difficulty in accounting for the conclusions which M. Verschovsky has reached. We ourselves have seen and analysed steel which was not only brittle, but which also readily disintegrated under blows, and gave both low tensile strength and low elongation, while on analysis it was almost ideal in its proportions of carbon, manganese, phosphorus, and silicon to make good rails. The difficulty with the steel was that it was improperly made. The sample which we have in mind was a special blow, made for a special purpose; its history was known completely, and we are confident that few practical metallurgists will disagree with the conclusion that if, at the end of the blow, sufficient time is not allowed to elapse to secure deoxidation, and if the metal is cast while it is still rapidly boiling, a steel will be produced which will not only be brittle, but also of low tensile strength, low elongation, and in every sense unreliable. We are free to confess that we would much prefer a hard sound steel to a soft unsound one. Our plea has always been for a sound, homogeneous, mild steel. Of course it is impossible for us to say that the above was exactly the case with the rails tested by M. Verschovsky, but the facts seem to us to point to a possible explanation of the conclusions which he has reached, and if our explanation is correct we should have very little difficulty in agreeing with his conclusions; our answer being, however, that a mild steel properly made is much better than a hard steel, which he praises.

4. Several years ago our attention was directed to the question of tires on locomotive driving wheels, which, as is well known, are made of steel. The question under discussion was the possibility of preparing specifications for locomotive tires, and, as a preliminary study, examination was made of a number of steel tires which had been in service. It may be stated here that for a number of years past the practical men in charge of the lathe-shops on different portions of the Pennsylvania Railroad where tires are turned off noticed, and have stated in conversation, that they always had to turn off the most metal from the softest tire; that is to say, when the tires come into the shop for re-turning, the very hard tires were the ones which had worn the most, the hardness being determined by the behaviour of the tool during turning. This, of course, was simply an observation, and very little positive data could be drawn from it. Following this suggestion, however, a number of tires were measured, the method being to take the circumference of two tires on opposite ends of the same axle. These tires, as is well known, are of practically the same size when they go into service, the variation being possibly not more than $\frac{1}{100}$ or $\frac{2}{100}$ inch in diameter between the two tires on opposite ends of the same axle. They also, as is well known, make the same number of turns, doing the same amount of service, and, barring the possibility of the engine getting a little out of balance, have practically the same pressure between the tire and the rail during their service. Again, if the driver-brake comes into account (all driving wheels do not have driver-brakes), its action is practically the same on the two tires on opposite ends of the same axle, so that it would seem that locomotive drivers afford an admirable opportunity for the use of the comparative method of making tests on the relative wear of hard and soft steel. In view of this consideration, a number of tires were taped as they came in from service to be re-turned, and in a short time three pairs of

tires were found which showed marked differences in circumference. The circumference was measured by putting a tape around the tire. In one case the difference in circumference was 2 inches, and in each of the other cases the difference was 1¾ inches. This difference in circumference corresponds to a difference in diameter of from 0·55 to 0·63 inch, or from 0·27 to 0·31 inch in the thickness of the tire itself. In other words, by actual measurement of tires which had been in service on opposite ends of the same axle, which were of the same diameter and circumference when they went into service, in the case of two of the pairs, one of the two tires had lost a little over ¼ inch of its thickness more than the other, while in the other pair one had lost nearly ⅓ inch more of its thickness than the other. In view of this discrepancy in wear under as nearly as possible the same conditions, it was with a good deal of interest that analyses were made of the metal taken from these tires. The result of the analyses are as follows:—

Analyses of unequally worn Tires, from opposite ends of the same Axles, on the Pennsylvania Railroad Locomotives.

	Least worn tire. Per cent.	Most worn tire. Per cent.
Engine 654—		
Carbon	0·594	0·708
Manganese	1·076	0·938
Phosphorus	0·039	0·101
Silicon	0·245	0·143
Engine 136—		
Carbon	0·541	0·625
Manganese	0·880	0·974
Phosphorus	0·062	0·063
Silicon	0·253	0·153
Engine 626—		
Carbon	0·525	0·554
Manganese	0·512	0·714
Phosphorus	0·032	0·037
Silicon	0·179	0·208

The tires of Engine 654 had a difference in circumference of 2 inches; the other two had a difference in circumference of 1¾ inches. It is interesting to observe that in every case the carbon is lowest in the least worn tire, indicating the softest steel, so far as carbon is concerned. Again, in two of the three, the manganese is lowest in the least worn tire. In one of the three there is quite a difference in phosphorus, the lowest being characteristic of the least worn tire, the other two having very slight differences in phosphorus. In two the silicon is highest in the least worn tire, while in the other the difference is the other way. Of course it is impossible to draw any very general conclusions from so small a number of samples as three, but the teaching of these results would seem to be that, in general, lower carbon and manganese and higher silicon are characteristic of tires which give the best wear. It is fair to say, in this connection, that it is not at all impossible that the temper of this steel may have an influence on the wear, apart from the chemical composition. It is well known that tires are "set," as it is called—that is, are fastened upon the wheel centre—by having the tire bored out to a diameter a little less than that of the wheel centre, and then heating the tire to expand it, so that it will take the wheel centre, and then cooling the tire. If, now, the tires are not heated to uniform temperatures, and cooled uniformly, or if they differ somewhat in their carbon, it is probable that one tire would have a different "temper" or "hardness produced by cooling" than another, and this might have an influence on the rate of wear. Of course, no positive data can be given on this point at the present moment. Before leaving the wear of tires, permit me one word further. Confining ourselves to the question of wear, it is difficult to conceive of anything which produces wear in rails different from that which produces wear in tires, since, if we understand rightly, it is a strain between the wheel and the rail which causes the rupture or tearing off of the small particles which we are accustomed to call "wear." It would seem, therefore, that tires afford an admirable opportunity for studying the question of relative wearing power of hard and soft steel, and the experiments alluded to in the early part of this paper are experiments on the wear of tires. A method has been devised, we think, and the number of hard and soft tires compared is sufficiently great, it is hoped, to enable very positive information to be obtained as to the relative power of hard and soft steel to resist wear. It would hardly be wise to enter into the details of the method of these experiments at the present moment, but it seems probable that within six months, or possibly a year, we may have considerably more light on the relative wearing power of hard and soft steel than we now have.

5. Our studies on wear have not been confined wholly to the behaviour of iron and steel under abrasion or rolling friction. A very large number of experiments have been made on the Pennsylvania Railroad with various alloys used as bearing metals, and instructive information may be drawn, we think, from these experiments as to the relation between wear and the chemical and physical properties of metal. If the experiments just alluded to may be trusted, and our deductions from them are correct, we find the same thing in the realm of the alloys which we have heretofore claimed with regard to iron and steel—namely, that those alloys which are least brittle, or, for want of a better word, those alloys which may be called softest, give the best wear—that is, they lose less metal under the same conditions than harder or more brittle alloys. Or, looked at in the light of definite physical properties, those alloys which give the slower wear are characterised by lower tensile strength and greater elongation than is characteristic of those giving more rapid wear.

The alloys experimented with have been principally the old copper-tin alloy (seven parts copper to one of tin), and alloys of copper, tin, and lead, with and without phosphorus and arsenic. It is not intended to say that no other alloys have been experimented with, but these are the alloys which have been most experimented with, and in regard to which we have the most reliable data. The method of experimentation has been to have a certain number of bearings made of a standard bearing metal, which will be described later on, and the same number of bearings of the experimental metal. These bearings were placed on opposite ends of the same axles, either on locomotive tenders or on cars, one half of the standard and experimental bearings being on one side of the car, and the other half being on the other side, but in all cases a standard bearing and an experimental bearing on opposite ends of the same axle. The bearings were all carefully weighed before going into service, and after a sufficient lapse of time were taken out and reweighed. At first an attempt was made to give the loss of metal by referring it to the mileage, but the method of comparison was ultimately adopted, as giving results free from any possible difficulties introduced by mileage, so that all the results which we obtained are strictly comparative.

The standard bearing metal is what is known in the market as phosphor-bronze bearing metal, technically described by the Phosphor-Bronze Smelting Company as the "S Bearing Metal." This metal contains approximately 79·70 per cent. of copper, 10 per cent. of tin, 9·50 per cent. of lead, and about 0·80 per cent. of phosphorus. It is, of course, a fair question, and one which has not been overlooked, whether the standard bearing metal gives uniform wear. A large number of experiments have been made on this point, the result being that the average wear of standard phosphor-bronze, compared with the mileage, is best expressed by saying that the phosphor-bronze bearing metal loses one pound of metal, worn off, for every 18,000 to 24,000 miles of travel. This, it will be observed, shows a discrepancy in the wear of the standard phosphor-bronze bearing metal, and the fact led us to abandon the method of making comparisons by mileage. The reasons for the discrepancy are not hard to find: First, the pressure per square inch in all tests were not the same, and consequently the wear would not be the same. On the other hand, with bearings on the opposite ends of the same axle, the pressures per square inch are approximately the same. Second, the state of the lubrication in different cars and engines, which is more or less characteristic of different parts of the road, is a very important variable, and undoubtedly goes far towards explaining the differences in mileage above given. This variation in the state of lubrication is not so apt to be characteristic of opposite ends of the same axle, as it is of different cars and locomotives. We are inclined to think, therefore, that the assumption that standard phosphor-bronze is sufficiently uniform in its behaviour to warrant its being used as the basis of comparison will not lead us into serious error, at least if we confine ourselves to a direct comparison of the loss of metal obtained from standard bearings on one end of the axles and experimental bearings on the other end of the same axles. Usually 16 bearings of each kind were put in service as a preliminary experiment, and if the metal proved at all favourable on this preliminary trial, a larger trial, embracing 50 or 100 bearings of each kind, was put in service. The preliminary trials were usually made on locomotive tenders, where the bearings get the best possible care. The larger trials were more commonly made on cars. Of course, owing to the exigencies of the service, it sometimes happened that some of the bearings put in use were not returned to be weighed. This was more true where bearings became heated, and were removed at different points along the line, than at the regular inspection points. Whenever, from any cause, a bearing was missing, its opposite was not taken into account, so that in reality, in the results given, the comparisons are strictly between the same number of standard and experimental bearings on opposite ends of the same axles. Sometimes as high as one-half the bearings in an experimental lot would be lost. In other cases nine-tenths would be returned. The results of the tests, with the composition, and, so far as our knowledge goes, the physical properties of the various alloys tested, are given below. It is unfortunate that in the earlier tests the physical properties of the alloys were not taken. In the composition, approximately average analyses are given rather than a special analysis of the metal in each test, and it will be observed that there is no allowance made for the small impurities, such as zinc, antimony, iron, &c., which are usually characteristic of commercial metals used in making these alloys, especially where some scrap is used in making the bearings, as is almost always the case. It will also be observed that, in all cases, in expressing the loss of metal by wear, the results are given in percentages of the metal lost by the standard phosphor-bronze.

COPPER-TIN *versus* PHOSPHOR-BRONZE.

	Composition Copper-Tin. Per cent.	Composition Phosphor-Bronze. Per cent.
Copper	87·50	79·70
Tin	12·50	10·00
Lead	None	9·50
Phosphorus	None	0·80

Wear.—First experiment, copper-tin wore 48 per cent. faster than phosphor-bronze; second experiment, copper-tin wore 53 per cent. faster than phosphor-bronze; third experiment, copper-tin wore 47 per cent. faster than phosphor-bronze.]

ARSENIC BRONZE *versus* PHOSPHOR-BRONZE.

(*First Experiment.*)

	Composition Arsenic Bronze. Per cent.	Composition Phosphor-Bronze. Per cent.
Copper	89·20	79·70
Tin	10·00	10·00
Lead	None	9·50
Phosphorus	None	0·80
Arsenic	0·80	None

Wear.—Arsenic bronze wore 42 per cent. faster than phosphor-bronze.

ARSENIC BRONZE *versus* PHOSPHOR-BRONZE.

(*Second Experiment.*)

	Composition Arsenic Bronze. Per cent.	Composition Phosphor-Bronze. Per cent.
Copper	89·20	79·70
Tin	10·00	10·00
Lead	7·00	9·50
Phosphorus	None	0·80
Arsenic	0·80	None

Wear.—Arsenic bronze wore 15 per cent. faster than phosphor-bronze.

ARSENIC BRONZE *versus* PHOSPHOR-BRONZE.

(*Third Experiment.*)

	Composition Arsenic Bronze. Per cent.	Composition Phosphor-Bronze. Per cent.
Copper	79·70	79·70
Tin	10·00	10·00
Lead	9·50	9·50
Phosphorus	None	0·80
Arsenic	0·80	None

Wear.—Arsenic bronze wore 1 per cent. faster than phosphor-bronze.

DAMASCUS BRONZE *versus* PHOSPHOR-BRONZE.

	Composition Damascus Bronze. Per cent.	Composition Phosphor-Bronze. Per cent.
Copper	77·00	79·70
Tin	10·50	10·00
Lead	12·50	9·50
Phosphorus	None	0·80

Wear.—First experiment, damascus bronze wore 8 per cent. slower than phosphor-bronze; second experiment, damascus bronze wore 7·80 per cent. slower than phosphor-bronze.

	Composition Alloy "B." Per cent.	Composition Phosphor-Bronze. Per cent.
Copper	77·00	79·70
Tin	8·00	10·00
Lead	15·00	9·50
Phosphorus	None	0·80

PHYSICAL PROPERTIES.

	Alloy "B."	Phosphor-Bronze.
Tensile strength, per square inch, lbs.	24,000	30,000
Elongation, per cent.	11	6

Wear.—Experimental alloy "B" wore 13·50 per cent. slower than phosphor-bronze.

If we interpret the above results correctly, they indicate: (1) that copper-tin wears nearly 50 per cent. faster than standard phosphor-bronze; (2) that arsenic bronze containing no lead wears about 42 per cent. faster than phosphor-bronze; (3) that arsenic bronze containing 7 per cent. of lead wears less rapidly, the exact figure being 15 per cent. faster than phosphor-bronze; (4) that arsenic bronze containing the same amount of lead as phosphor-bronze wears but slightly faster, the figure being 1 per cent.; (5) that damascus bronze containing as high as 12·50 per cent. of lead wears from 7 to 8 per cent. slower than phosphor-bronze; and (6) that the experimental alloy "B," containing less tin and more lead than any of the other alloys experimented with (the figures being 8 per cent. of tin, and 15 per cent. of lead, instead of 10 per cent. of tin, and 9·50 per cent. of lead, as is characteristic of phosphor-bronze) wears 13·50 per cent. slower than phosphor-bronze. This last alloy is the only one of which we have the physical properties compared with phosphor-bronze, and it will be observed that it has considerably lower tensile strength with greater elongation than the phosphor-bronze. This characteristic of lower tensile strength and greater elongation, it will be remembered, is the same characteristic which has been so often alluded to in the case of steel—namely, that mild steel, which, as is well known, is characterised by lower tensile strength and greater elongation than harder steel, gives the best wear. Here, too, in the realm of alloys, that metal which gives the lower tensile strength and greater elongation, if our experiments can be trusted, gives the slower wear. As has already been stated, it is unfortunate that the physical tests of all the other experimental alloys were not taken; but there is another method of getting at the physical properties of these alloys which is instructive, and although not as definite, is, perhaps, almost as convincing as though the actual figures were given. It is well known that the alloy of two parts of copper to one of tin, which is commonly called speculum metal, is one of the most brittle substances known. If, now, the percentage is changed, and an alloy is made of three parts of copper to one of tin, it is less brittle than the first one. Four, five, six, seven, eight, &c., parts of copper to one of tin give alloys which are in every case less and less brittle as the tin diminishes, if our data can be trusted. It is well known that the alloys of four, five, six, and sometimes seven parts of copper to one of tin are used for making bells for various purposes. The alloy of seven parts of copper to one of tin is the copper-tin alloy used as bearing metal in our experiments. If this reasoning is correct, the law seems to be, that the increase in copper, and the diminution in tin, at least within the range of our experiments, give alloys which are less and less brittle in every case. In the experiments which we have made, it will, of course, be urged that lead comes in as an important constituent in the alloy, and consequently the query arises, What influence has the lead on the alloy? The influence of the lead has not been worked out in figures to our knowledge, but so far as our observation and study have gone, the addition of lead practically amounts to the same thing as a still further diminution of tin—that is to say, an alloy containing any given percentage of copper and tin will be rendered more ductile and less brittle by the addition of lead to this alloy, which, if our reasoning is correct, is the result which follows a diminution of tin and an increase of copper. I have, in another place,* tried to illustrate this subject at some length, and will not, therefore, at this time dwell longer upon it, except to say that in the only case in which we have a physical test of these alloys—namely, in the case of phosphor-bronze and the experimental alloy "B"—this law seems to be fairly well illustrated. In the standard phosphor-bronze, the ratio of copper and tin is very nearly one to eight, while in the experimental alloy "B" the ratio of copper and tin is about one to nine and six-tenths. The percentage of lead in phosphor-bronze is 9·50, and in the experimental alloy "B" 15 per cent. The marked influence of these changes on the tensile strength and elongation is very clear. The tensile strength is cut down 6000 lbs. per square inch, or about one-fifth, and the elongation is increased to nearly double that of phosphor-bronze. I will add for information that the experimental alloy "B," with a slight modification so as to enable the foundry to use the large quantities of phosphor-bronze scrap which the Pennsylvania Railroad possesses, and which results in giving from 0·10 to 0·20 per cent. phosphorus in the finished bearing—the percentage of the other constituents being those given above—is now the standard bearing metal of the Pennsylvania Railroad, and no information has been obtained, during some six years of constantly increasing use of this metal, which would controvert the conclusion given above, that the experimental alloy "B" wears slower than standard phosphor-bronze. It is possibly hardly necessary to add that we are not able to draw from our experimental work in the realm of alloys any other conclusion than that those alloys which are least brittle, or, measured in technical language, which have lower tensile strength and greater elongation, give better wear as bearing metal than those alloys in which the reverse is the case; or, in other words, that in the realm of the alloys, so far as our experiments have gone, the same thing holds true which we have heretofore found in regard to steel—namely, the softer metal gives the better wear.

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* *Journal of the Franklin Institute.*

A few points further in regard to wear. We are not aware that any attempt has ever been made to formulate the variables on which wear depends, or, in other words, to enunciate a theory of wear; and it is entirely possible that the data in our hands, which are reliable enough to be so used, are not at all sufficient to warrant us in making such an attempt. Our observations, however, have led us to philosophise on this subject, and at the risk of saying something which future experiments may very greatly modify, or possibly show to be fallacious, we will venture to state a few of the variables which enter into wear.

Of course, wear is influenced by the conditions under which it takes place, but it is not our purpose to discuss these variables, which may fairly enough be called "concomitant conditions." We will, therefore, not discuss lubrication, pressure, speed, temperature, rolling friction, or abrasion, nor, indeed, the nature of the two metals rolling or sliding over each other, but will confine ourselves wholly to the qualities of metal which, all other things being equal, give least loss of substance by wear under the same service. To our minds, we are justified in assuming that at least three elements enter into the problem of wear.

1. That metal which will suffer the most distortion without rupture will wear best. This quality of metal is usually measured or expressed in figures by the well-known physical data "elongation" or stretch before rupture in the common physical test. Possibly the experimental data on this point is greater than we possess on any other of the variables which enter into wear. If we may trust the data which we have brought forward, and the conclusions drawn from them, in all cases the greatest elongation is characterised by the best wear; or, according to the law, that metal which is characterised by the greatest power to resist distortion without rupture will wear best.

2. The first variable being obtained in satisfactory amount, an increase in tensile strength will add to the wearing power of the metal. The diminution of tensile strength, which is characterised by the better-wearing metals, according to our data, is not, if we are correct, a desirable quality. It is a concomitant of most metal that as it increases in its power of elongation, or stretch, before rupture, it diminishes in tensile strength. If, on the other hand, a new metal could be found which, with any given elongation, was characterised by a higher tensile strength than some old and well-known metal with the same elongation, the new metal would, if the theory is correct, wear better than the old one. It is not difficult to say why an increase in tensile strength should be valuable in assisting wear, provided the power of distortion before rupture is not interfered with. Wear, as we understand it, is the tearing off of minute particles, and if in one case it requires more force to tear off the particles than in another, the wear in that case will be slower. We have, we think, a little

experimental data which point in this direction. The wear of bearings per thousand miles is about three times as fast as the wear of axles; in other words, as has already been stated, the standard phosphor-bronze bearing metal loses about a pound for each 25,000 miles that the bearing moves. The axle under it loses about a pound for each 75,000 miles, but the metal of the axle is from two to three times as strong per square inch, and its elongation is also somewhat higher than the bearing metal alloy.

The third variable which enters into wear, as we look at it, is what may perhaps be termed the "granular structure of the metal." This may, perhaps, best be illustrated by saying that, of two metals which have the same tensile strength and the same elongation, the one which is finer in granular structure will wear the slower. This, we think, will be evident by returning to our conception of what wear is—namely, the tearing off of minute particles from the worn body. If, now, at each rupture of a particle of metal, the particle torn off is in one case twice as large as in the other, the wear will be twice as rapid, and we assume that, other things being equal, the granular structure represents the size or fineness of the particles torn off at each operation during wear. We have only a little experimental data on this point. It is generally believed by those who have a chance to make observation, that what is known as case-hardened iron wears better than either the wrought iron from which it is made, or than ordinary hammered steel of approximately the same carbon. It has also been observed that case-hardened metal is always characterised by an extremely fine granular structure, as evidenced by the fracture. This, of course, is only an observation, and cannot be taken as proving very much. It is also entirely possible that the influence of what is technically known as "tempering," on wear, may appear in the effect of the temper on the granular structure. The field is, of course, too void of experiment and too little known to warrant anything more than suggestions.

The relation and interaction, so to speak, of the three variables mentioned above is, of course, quite an unknown field. We are inclined to think that the experimental data which have been obtained point clearly to the conclusion that the increase in tensile strength at the expense of elongation is disastrous, as far as wear is concerned. An increase in tensile strength, with an increase in elongation, would unquestionably, we think, be valuable. The influence of the structure or granular condition may be even more important than either elongation or tensile strength. Of course, the data do not warrant any conclusions, but it seems not at all improbable that the size of the particle torn off, each time one is torn off, may be the most important variable in the rate of wear. It is also not improbable that if some method of measuring the granular structure of metal, and rightly estimating its influence on wear, was known, this information would go far toward explaining many of the anomalous cases of wear which, if our experience is worth anything, are almost universal accompaniments of experiments in this field.

The whole subject of the relation between wear and the chemical and physical properties of metal needs study and positive experiment, and it is quite possible that much that we are accustomed to rely on at the present moment may be upset or overthrown by wider knowledge. The best we can say at present is, that, with the light which we have, the highest tensile strength, accompanied by the highest elongation and the finest granular structure, are the physical properties which will probably give the best results in actual service, where the metal is subjected to wear, and that that chemistry which will give these results in the finished product, be it in the realm of the alloys, or in the magnificent field of steel metallurgy, or, possibly, in the coming field of a metallurgy based on aluminium, is the best chemistry which we, at the present moment, are able to recommend.

DISCUSSION ON MR. DUDLEY'S PAPER.

Sir **Lowthian Bell**, F.R.S., said he had listened to the paper with much interest. It happened that the President and himself were members of the Locomotive Committee of the North-Eastern Railway, 1500 miles in length, and therefore affording ample scope for making any inquiry bearing upon the question then submitted to the meeting. In one point he entirely agreed with Dr. Dudley, and that was the difficulty of assigning a true cause for the differences which were observed in the wear of rails. He might mention that upon the North-Eastern Railway they followed at first to a great extent the advice given to them by the manufacturers of the rails themselves. They were of the opinion that in all probability it would be found that the softer the rails were, the stronger they were; and the North-Eastern Company continued to use rails containing not above 0·3 per cent., more or less, of carbon. Their engineer at that time (a gentleman of great experience, and greatly respected for the use he had made of that experience) and himself, and other members of the committee, frequently discussed the question as to whether they might not, with advantage to the railway, increase the quantity of carbon in the steel, with a view to increasing its hardness, and, as they expected, increase its resistance to wear upon the railway. Accordingly, on their advice, the Board of Directors consented that their rails should be raised from 0·3, or thereabouts, to 0·5 per cent. of carbon. They had continued for some years to have their rails guaranteed by the makers to contain that quantity of carbon. He could not say that they had had sufficient experience to enable them to pronounce very strongly as to the benefit which they hoped to derive from that change; but this much he thought he might say, that if any reason existed for a contrary line of conduct, it had not up to that time made itself very apparent to themselves. Certainly the danger apprehended by some, viz., dangerous brittleness, had not been experienced.

The question of comparative durability might seem a very simple one; it was one, however, which was replete with difficulty. The conditions to which the rails were exposed had altered materially in recent years. Dr. Dudley mentioned what the wear of rails had been during a certain number of years upon the New York and New England Railway. If they were to collect the statistics of their own line in that way, they would have a variety of very discordant results, for the reason that not only had the traffic upon their line greatly increased, but (what perhaps was of more consequence so far as the wear was concerned) they had greatly increased the weight of their locomotive engines, a change which necessarily entailed greater wear on the rails. Keeping this in view, he was very anxious to establish a rapid mode of ascertaining the relative wear of rails having a different composition, and he directed the superintendent of their locomotive department to construct a machine in which, by the rapid revolution of a wearing surface (a kind of grindstone, in point of fact), they might, in a few weeks, compare the results of actual loss of weight of a rail. Like most mechanical contrivances, at first, at all events, perfect success did not attend their investigations with the apparatus used; but they were not going to relinquish it on that account. He might say that he heard with very great surprise the statement of the amount of carbon contained in locomotive tyres. Mr. Hadfield could perhaps give them some information upon that subject, but, so far as he knew, they had no tyres running upon the North-Eastern Railway of England in which the carbon was as high as 0·6 to 0·7 per cent., and usually their locomotive tyres contained very little more than half that quantity, say about 0·45, while their wagon tyres contained about 0·35 per cent. of carbon. However, it was perhaps premature to declare very strongly any opinion upon that subject until they had had more experience than they had received up to that time. Their North-Eastern line, as he had mentioned, was about 1500 miles in length, and of that stretch he should say that something like 1400 miles were laid with steel rails, and whenever a rail was broken or whenever a fracture took place, the rail was brought into the chemical laboratory of the Company, and an accurate analysis was made of its composition. He thought on that point he agreed entirely with Dr. Dudley—that all the chemical information they had got up to that time had entirely failed to throw the slightest light upon the cause of the fractures. He was inclined to think that it might be due rather to the occurrence of that critical condition spoken to upon this and other points of the rail, or, in other words, due to questions entirely different from that of chemical composition, and that the rail had been cooled either too suddenly or too slowly. At all events, *qua* chemistry, they had not been able to trace a fracture to any chemical cause.

The **President** said that time would not permit of any further discussion, but the matter would be considered again at the next meeting, when they hoped to hear something from Mr. Snelus, Mr. Price Williams, Mr. Aspinall, and others. Meantime he asked for a cordial vote of thanks to the author of the paper.

A vote of thanks was given by acclamation.

Votes of Thanks.

The **President** then proposed, "That the best thanks of the Iron and Steel Institute be given to the President, Council, and Secretary of the American Institute of Mining Engineers; to the American Iron and Steel Association, and the bodies who have been associated with them in the invitation to hold this meeting of the Institute in the United States; to the President, Members, and Secretary of the General Reception Committee, for the very complete, thoughtful, and hospitable arrangements made for our present meeting; to the Local Reception Committees in Philadelphia, Pittsburgh, Chicago, Birmingham, and other places to be visited by the Institute, for the courtesies extended to the members in connection with the several excursions; to the proprietors of the iron and steel works, mines, collieries, and other establishments so generously thrown open for the inspection of members; to the American railway, steamboat, and transportation companies who have afforded special facilities for the several excursions undertaken by members of the Institute; and to the ladies of New York and other cities, who have organised special committees to provide for the accommodation and convenience of the ladies who have accompanied the members on the present occasion." He should have liked to have dwelt at length on these facilities, and on the extraordinary manner in which they had been welcomed and entertained, and were to be entertained, throughout the United States. He thought that that reception was unique. Indeed, it was one of the "firsts" of the present age. He moved that vote of thanks, constrained by time not to offer any further observations, and he asked them all to vote for it by acclamation.

The motion was unanimously adopted.

Mr. Hugh Bell said it had fallen to his lot, by the courtesy of the Council, to ask them to perform the last formality before they closed the meeting of the Iron and Steel Institute held in the United States of America. He was invited in the spring of that year, in London, to support Lord Granville in asking the members then assembled to accord to their President a vote of thanks for the manner in which he had discharged his duties there; and in speaking to that resolution, he assured his Lordship that he, who had not had the advantage of sitting under the presidency of Sir James Kitson, need have no hesitation in speaking, as he did, in terms of high praise as to the manner in which Sir James had discharged the duties of his office. On that occasion he ventured to prophecy (because he knew) and he said that, having had the experience of Sir James Kitson's presidency in Paris, and then in London, he felt certain that the brilliant record which he was then making would be broken again and again by the way in which he would fulfil the duties of his office when he came to the United States of America. He, the speaker, felt confident that they would bear him out, when they returned to their native land, in saying that of all the meetings which the Iron and Steel Institute had ever held, none could compare to those which had been held under Sir James Kitson's presidency, and that none could compare in the least degree in brilliancy with that over which he had presided in the United States of America. Before him it would be unbecoming to pass that eulogy which one to another they were passing on Sir James, but he might be permitted to praise the tact, discretion, and ability with which he had discharged the difficult and onerous duties of his position. As Englishmen, they had been proud to be represented in the United States by one who had upheld their character so nobly, and with so much judgment, as Sir James Kitson had done; and he asked them accordingly to pass the following resolution—"That the best thanks of the Iron and Steel Institute, in public meeting assembled, be and are hereby tendered to the President, Sir James Kitson, Baronet, for the courteous and able manner in which he has presided over the present meeting."

The resolution was adopted by acclamation.

The PRESIDENT, in reply to the cordial vote of thanks, said: Yesterday, when Mr. Hewitt read his address in acknowledgment of the presentation of the Bessemer medal, he made a comment which was somewhat painful to him, because he believed many of them were aware that he was elected to that chair as the representative of the best Yorkshire iron trade. Steel had had so much of its own way, that it was felt to be only fair that wrought iron should have once more an opportunity to assert itself. But what did Mr. Hewitt say? He said, with reference to wrought iron, "It is evident that this commodity will soon be regarded as a relic of the past." He was there as the representative of this relic of the past. And Mr. Hewitt added, "although in some special branches its use will survive, serving to remind us of processes which otherwise would have been consigned to history." He was there, therefore, as a relic of the past, serving to remind them of a metal which in its time had done great service; and if in representing that metal, that ancient relic, he had been able to afford them any service, he could only say that he was very glad, and deeply grateful to them for their recognition of it.

The proceedings of the New York meeting then terminated.

The five papers that follow were prepared for the New York meeting of the Institute, but owing to the limited time available, they had to be taken as read.

FUEL GAS AND SOME OF ITS APPLICATIONS.

BY BURDETT LOOMIS, HARTFORD, CONN.

THE advantages of gaseous fuel have been too fully set forth during the past few years to need recapitulation. Papers, arguments, and editorials have been issued, in a more or less general way, that would make volumes. Systems have found zealous advocates, and promises of results made, that have sounded strangely in the ears of old-fashioned gas-makers, have been born of theory, and have died in the earliest throes of trial; while in some few instances success has demonstrated the value of practical effort. With few exceptions, however, everything attempted or accomplished has tended towards the one end,—the realisation of more perfect results than we can obtain with the direct use of solid fuels; and there are to-day few to dispute the coming supremacy and general use of gaseous fuel.

It is not assumed that the solid fuels will be wholly superseded; such an assumption would be folly, as there are circumstances in which solid fuels must continue in use, from necessity or economy. These, however, are few, and can almost be named in a breath; while the purposes for which the gaseous fuel is not only cheapest, but best, are so many as almost to defy enumeration. Wherever constant high-flame temperature is necessary, the gaseous form must find precedence, while its easy carriage to long distances and its attainment of maximum temperature almost instantaneously with ignition, give it a leverage that is scarcely covered by that easy term—convenience.

The discovery and application of natural gas has not only borne the weightiest of testimony on behalf of the general necessity for fuel gas in nearly all fields, but it has done more. Its wide scope of service, from the great establishments wherein thousands use it constantly, to the cottage where it saves countless steps for the housewife, has demonstrated the necessity for a gas of general application, that will fulfil all the demands of the manufacturer, and meet the wants of the domestic user. The fuel gas that is to score a wide success must fill these conditions. For a gas that will not, the field is limited.

In the manufacture of a fuel gas, then, it is obvious that certain conditions are primarily necessary.

As concerns the apparatus to be used, these are:—

1. *Simplicity.*—It must be easily and cheaply worked, and require a minimum of skilled labour.

2. *Durability.*—It must do its work with but little repair or replacement.

As to the material to be used in the manufacture of the gas, the conditions are:—

1. *Richness.*—It must contain the necessary carbon.

2. *Cheapness.*—It must be generally obtainable in large quantities at low prices.

These qualifications are met by the slack or fine bituminous coal, which are the least expensive of all coals, and are obtainable in nearly all markets at low rates.

These points established, it remains to decide upon the kind of gas to be made. This must be calculated to meet all the wants of those for whose uses it is intended. Here we find it necessary to consider the following:—

1. *Quality.*—The gas must contain all the carbon possible, consistent with the other necessary conditions.

2. *Cost.*—It must be low in cost, especially in view of its use in large quantities.

3. *Cleanliness.*—It must be as free as practicable from impurities, and must be clean as regards the more perceptible.

4. *Transmission.*—It must be capable of easy carriage to reasonably long distances, and through small, as well as large, pipes.

5. *Temperature.*—It must have a constant high-flame temperature, and must ignite under all conditions, when desired.

For general adaptability to the wants of all classes of consumers, the requirements named must be met, and the more completely met, the greater will be the success of the gas offered.

In many cases, a good producer-gas accomplishes all that is needed, and, used in a well-constructed regenerative furnace, is much cheaper than coal; but its usefulness is confined to places where such furnaces can be constructed, if high-flame temperature is required, or where low heats are sufficient, and obtained without regeneration. Outside of such confines, it is not economical, and is seldom useful.

Without discoursing on the relative merits of other gases, I believe that the gas best suited for general fuel purposes is water-gas. Its flame temperature is high, it is cleanly, reasonably free from impurities, and it can be transmitted to long distances.

The one possible factor to which objection might be made is its cost. If it meets this requirement, there is no further bar to acknowledgment of its claims. Can it be made from the cheapest of materials offered in the general market for gas-making purposes? In discussing the lions in the path of success in this direction, the *London Journal of Gas Lighting*, some months ago, pronounced the following ultimatum:—

"The slack, however wet, dirty, dusty, sulphurous, or stony, should be tipped into the hoppers of the gas-making cupolas, and gasification should go on continuously and completely, so that nothing but gas and ashes should remain of the material put into the apparatus."

This can be done, and is done, in many places, with the Loomis apparatus, which is using the cheap coals mentioned, as well as the more expensive anthracite coals and coke. This apparatus is the only one that I know of in successful operation making water-gas directly from the bituminous slack coals that are found in abundance in many parts of the world. It is a simple fuel gas-generating machine, and it will not only make as much water-gas from a ton of this slack coal as can be produced by any other method from the same quantity of anthracite or coke, but it also utilises the blast gases for making the steam necessary to run the engines and exhausters, and for decomposing, leaving a surplus for other work; or the blast producer-gas or generator-gas can be used in regenerative, reheating, annealing, melting furnaces, &c. For these purposes, the producer-gas made by this apparatus answers all requirement, as can be shown by demonstration in the several places where it is so used.

Water-gas generators, to be economical producers of gas, must be so constructed that they will continuously make a first-class quality of gas for the full period of a twenty-four hours' run. In all the generators using the up-blast system, after a few hours' run the quality of the gas has become much poorer than at the beginning, when the fires were fresh, on account of the clinkers and ashes that accumulate.

In the Loomis generator this is obviated, and the gas is of as good quality at the end of a twenty-four hours' run as at the beginning or any part of the run. This is due to the peculiar construction of the generator, and the action of the exhauster in collecting the ashes at the bottom of the fire and in the ash-pit. In the process of exhausting before making a run of water-gas, this is highly heated and useful for superheating the steam before it strikes the incandescent coal, and in this way the carbon is nearly all extracted from the coal, less clinker is made, the gas is freer from carbonic acid, and increased production is obtained.

In the matter of quality, a high grade of product should be aimed at, and the water-gas made as pure as possible, so that it can be used, where practicable, without purification. In works where it must be purified, the better the quality of the gas the less the expense for purifying.

The claim has been made that the water-gas that can be made from a given amount of coal must be less economical than the coal used directly, both on account of the smaller number of units of heat contained in the gas and the labour and expense of making. Where coal can be well fired, and gases economically burned direct from the furnace, this is in many instances true, but the great fields for water-gas lie in the special uses for the many kinds of metallurgical work and kindred work where coal directly used cannot enter as a comparative factor, and for domestic purposes, where the gas is proving itself as cheap as the coal, if not cheaper, while it accomplishes results that are not obtainable with the solid fuel.

In estimating the economy of its general uses, another factor must be considered. This is application. In this particular, the threshold of investigation has scarcely been crossed, yet much has been accomplished, while the future is fruitful of certain realisation. Until lately, the gas has not been obtainable for the purposes of experimenting in large quantities, and as yet, in special work, the methods of application are comparatively crude. Within the past few years, however, much has been done in the face of untoward circumstances, and you can now be shown the gas in use in many ways where it has supplanted coal, and wherein it has been found more economical than to fire coal, without taking into consideration any other features of advantage.

In nearly all branches of metallurgical work wherein the gas can be applied, however, there is found:—

1. An increased product.
2. A better grade of product.
3. Direct economy in cost.

Increase in amount of product arises from the saving in direct labour, as can be most easily seen, perhaps, in forge shops and the like, and from the gain in the personal condition of the workmen, owing to the increased healthfulness of their surroundings.

The gain in grade of product arises chiefly from the uniformity in the temperature and the quality of the fuel.

The economy in cost needs no explanation. I may state, however, that in some large works which have changed from coal to the use of fuel gas, the gain in direct economy has been proven to be from 33⅓ to 50 per cent. in labour and over 40 per cent. in fuel.

In many instances, the gain from having a sharp, quickly heating flame, is such as to overbalance the question of more direct saving in cost of production, and it is not infrequently demonstrated that, by this means, workshop material enough is saved to alone pay all the productive cost of the gas.

Another feature worthy of consideration is economy of space in locating furnaces or other appliances for the use of the gas, especially where it is desirable that these should be grouped together as closely as possible. It also renders possible the location of furnaces, heaters, forges, &c., just where desired, without necessity for considering the questions of convenience that frequently arise where there must be either coal carriage or storage.

With this, too, may be considered the fact that the heat from the gas is brought under closer control than that from the coal fires, and there is less heat generated into the room or space surrounding the point of application. This perhaps may seem of minor importance, but in these days of sanitary investigation and of shortening the days of labour, it will be found no little advantage to keep the temperature of the workroom as far as possible under control.

In many parts of the world inventors are devising new applications of this gas, and with marked success. It is so well made and so easily handled, that its application in many new channels amounts to little more than ordinary manipulation and direction by those who understand the work to be done.

Among the several places in this country where the gas made by the process I have named has been applied to such a variety of uses as plainly shows its adaptability as a general fuel, as regards both efficiency and cost, are the saw-works of Henry Disston & Sons, which you will be invited to examine on your journey from New York to Philadelphia. There you will see the generators at work on steady and continued runs, and will see the two gases, *i.e.*, the water-gas, and the producer-gas that is made intermittently with the water-gas, both carried to holders, and delivered under pressure at different parts of the works.

This is the first place of which I have knowledge where producer-gas has been stored in a holder, and thence delivered cold to different furnaces at distances from the generators, being fired cold at such distant points. The process of manufacture and the manifold utilisation of the different gases, but especially of the water-gas, will be of interest. Full facilities for a thorough examination of the process of manufacture will be given, as well as full liberty to make any tests or experiments desired.

Estimated cost of 1,000,000 *feet of water-gas based on actual results, coal at* $3·00 *per ton.*

	$
Coal, 25 tons, $3·00 per ton	75·00
Coal for steam, 3 tons, $3·00 per ton	9·00
Labour	22·00
Extra for supplies and repairs	4·00
Purifying	5·00
	115·00
Received for producer-gas	40·00
	75·00
Interest on plant and depreciation	25·00
	100·00

Cost per 1000 feet, $0·10.

In the practical using of water-gas, 20,000 feet often accomplishes better results than a ton of coal directly fired; in some cases more is used.

This has been accomplished by new and improved methods of application, and will be improved upon as necessity demands and appliances are perfected.

I may say, in conclusion, that in no place where this gas has been put into use has any thought been given to a return to coal. The solid fuel, once supplanted, will never be sought for again.

Description of the Loomis Generator.

Figures 1 to 4 show the way in which producer-gas and water-gas are made alternately.

In bringing the coal to an incandescent state for making water-gas, the door A is open, and the exhauster E is started and draws the air down through the coal and ash-pit and up through the cooling boiler, and the producer-gas made by this operation is forced through the pipe C to the holder.

When the coal is in a proper state for decomposition of steam the exhauster is stopped, and the door A shut, and steam is let on at the valve B at point X, and it passes through the ash-pit and grates, where it is highly superheated, then through the mass of coal, making water-gas, which passes out at P through the seal box N to the water-gas holder.

After a run of about five minutes, the steam is shut off, the door opened, the exhauster started, and the process of making producer-gas is again commenced.

Since the foregoing paper was written, the following actual results have been obtained in melting brass in crucibles with water-gas, using an improved furnace:—

In melting 2000 lbs. of brass in 100-lb. crucibles, 12,000 cubic feet of water-gas was consumed.

In using the same size of crucibles in works that are melting from five to ten tons per day with coal, it takes 2000 lbs. of coal for 2000 lbs. of brass.

Units of heat in 12,000 feet of water-gas used, 3,600,000.

Units of heat in 2000 lbs. of coal used, 27,000,000.

Or seven and one-half times the amount that is in the gas used.

One ton of coal will make 40,000 cubic feet of water-gas, which will accomplish as much as 3⅓ tons of coal in this work.

The cost of labour in making water-gas will be less than in firing coal direct. The producer-gas made, in addition to 40,000 feet of water-gas from a ton of coal, will yield all the steam needed, and pay interest and repairs on the plant.

The coal used for making the gas, being bituminous slack, only costs two-thirds as much per ton as that used with direct firing.

One ton of coal to make the gas, costing $3.00.

3⅓ tons at $4.50 per ton will cost $13.50.

Saving on coal in melting 3⅓ tons, $10.50.

As it only requires two-thirds the time to melt with gas that it does with coal, there is a great saving, and less space is needed for furnaces, as only one-third the number are needed. Metal is not wasted in the ash, and crucibles will last much longer.

ON SPIRALLY-WELDED STEEL TUBES.

BY JAMES C. BAYLES, PH.D.

THE ideal pressure tube is, obviously, the one which combines the greatest strength with the least weight of material consistent with the uses for which it is designed or employed. The inside of the pipe is the first concern of the engineer. It should be cylindrical, smooth, and of the requisite capacity for the purpose in view. It should be in lengths as great as can be conveniently handled, so that the couplings may be as few as possible. With the walls of the tube the engineer has no further occasion to concern himself than to make sure they are adequate to carry the internal and external pressures to which they will be subjected. It is as true of a pipe as of a truss, that when it is strong enough to give the requisite factor of safety, nothing is gained by having it stronger. Anything more than this means dead weight, which has to be paid for many times, first as material, and again and again in the costs of transportation and handling until it reaches its place in the trench or on supports. In use it must be and remain tight against all leakage, and must sustain whatever is placed over or upon it, or suspended from it, without deformation or injury. Finally, in addition to meeting all the immediate requirements of service, it must possess qualities of durability which warrant a reasonable expectation of a long life of usefulness. The wise engineer no longer regards it as reasonable to depend upon mere bulk of its own material for the protection of a metal as readily impaired or destroyed by oxidation as iron or steel. The metal must have a coating which will be and remain impervious and indestructible. When all these conditions are met, we have as near an approach to the ideal tube as can be attained with the materials now available for their manufacture. Steel used constructively, to the best advantage, meets these requirements most perfectly. Gold alone would do it better. If we search through the whole list of metals and alloys we find nothing available which so perfectly meets the requirements as a pipe material as steel.

Mr. Hamilton Smith, jun., in a paper on the expedients adopted on the Pacific Coast in the extensive schemes of hydraulic engineering, for which that part of the world has long been famous (*Transactions of the Iron and Steel Institute*, vol. i. 1886), thus states the conclusions to which his observations have led him:—

"The ideal conduit for high pressure is a welded steel tube. Such tubes could probably be subjected to a tensile strain of 25,000 lbs. with perfect safety, and would be much preferable to riveted pipe: not only on account of superior strength, but also by reason of almost perfect interior smoothness. . . . The adaptation of a superior and cheap metal, such as mild steel, for conduits, will permit the construction of hydraulic works in many parts of the world, which now appear to be impracticable, owing to the cost of many of the methods now in use for the transportation of water."

The accuracy of this generalisation is not surprising, considering the opportunities afforded Mr. Smith for the study of this question, where substitutes for the hitherto impracticable light welded pipe of iron or steel have been used most extensively and successfully. The manufacture of light steel tubes by the processes employed in making the heavy tubes to which we have become accustomed, has been found impossible for mechanical reasons. With the weight of metal needed to carry a welding heat from the furnace to the rolls, the pipe produced is necessarily heavy. Hence the extensive employment of riveted pipes during the past few years, not only on the Pacific Coast, but all over the world, and of which the best that can be said is that they have been used simply because nothing better was available.

Some twenty years ago an ingenious American engineer and mechanic, the late John B. Root, conceived the idea of making light and strong tubes by spirally winding bands of iron or steel, so that the edges should overlap, and of heating the overlapping edges and welding them together during the forming process. The novelty of this idea consisted in confining the heat to the edges to be united, and welding the seam as the pipe was formed. The obviously greater strength of a tube thus made over one having any form of longitudinal seam, had already attracted attention. Many years before, as appears from English Patent Office records, an attempt had been made to produce a pipe having a helical weld. The blank was wound cold with overlapping edges, and placed in a furnace to be heated. When the welding temperature was reached it was drawn out, and an attempt was made to weld it on a mandrel by the pressure of rolls, externally applied. The experiment, though interesting, was hopelessly impracticable. To carry a welding heat from the furnace to the rolls, the material operated upon needed to be of a gauge so heavy as to render it impossible to cold-wind it. Furthermore, it was impossible to keep the diameter uniform, as with every turn of the skelp it gained in size an amount equal to the thickness of the metal used. The problem was not at all akin to that of making the twist gun-barrel; and after it was found that tubes could not be made in this way, the experiment was abandoned.

When Mr. Root began his experiments, he probably had very little idea of the difficulties involved in accomplishing what now seems so simple. He began by cold-winding, and his first invention in this line was one which has had great value; I refer to the spirally-riveted pipe. The machines for making this form of pipe, though never quite automatic, were very ingenious, and have done good service. They wind the metal, punch holes in the overlapping edges, and as the rivets are dropped in by hand, head them by compression. The process is obviously limited to the use of small and soft rivets, which can be "upset" cold by compression sufficiently to hold them in place. That pipe thus made has any greater utility than ordinary stove pipe, is due to the fact that its seam is so disposed that it is not readily opened by an internal pressure exerted circumferentially. This form of riveted pipe is made of material too light to be caulked, consequently it depends for tightness wholly upon the coating of zinc or coal-tar given it. As a preservative coating for either iron or steel, zinc has little value; but it serves very well as a solder to stick the lapped edges together, and make a riveted pipe tight against any pressures not exceeding the strength of the material at the line of the rivets. The black coating, when properly made and applied at a temperature sufficiently high, also answers very well to close the seam against light pressures. In some places this pipe has rendered excellent service; in others it seems to have failed conspicuously. I presume its life depends largely upon how it is laid, and upon a light and measurably constant pressure. From its construction I should not expect it to stand shocks without developing leaks. As a matter of fact, however, the spiral-riveted pipe has been largely employed, and it is still manufactured extensively.

During some ten years Mr. Root continued his experiments amid many discouragements. It was not until 1883 that he succeeded in building a machine which, in a rude way, demonstrated the practicability of making pipe from strips of iron wound spirally, heated along their overlapping edges only, and united by hammering. This machine, which is carefully preserved as a mechanical curiosity, is a marvel of ingenuity, but not at all practical commercially. Mr. Root had throughout made the mistake of supposing that he was dealing with a mechanical problem simply. That he overlooked the chemical factors is evident to those who, after his death, took up his work and made it successful. It is true, however, that he produced some pipe in short lengths, and that, owing to the slip of the feed and other mechanical defects in his machine, some of this pipe was of surprising smoothness and beauty. That very little of his experimental pipe was really welded was due to causes for which, as a mechanic, it probably did not occur to him to look.

At Mr. Root's death, which occurred before he had fully worked out the problem to which he had devoted so many years of patient labour, it was found desirable to depart radically from the lines of his experimentation, and to supplement his work by original investigation in many directions. For the purposes of this paper it is sufficient to describe the method of manufacture now employed, which represents the present state of the art.

The only material now used in the manufacture of spirally-welded tubes is mild steel. This is at once stronger, cheaper, and more uniform in quality than any iron available for the purpose, and owing to its homogeneity and density it resists destructive oxidation much better than iron of fibrous texture. Either Bessemer or open-hearth steel is used. The specifications as to composition are not arbitrary. Phosphorus is not considered, being low enough in any steel yet tried. The carbon must be so low that the metal will not harden or become brittle when as suddenly as possible cooled with water after the weld is made. The sulphur must not be high enough to defeat welding, and copper must not be present at all. The steel employed has an average elastic limit of 35,000 to 40,000 lbs., and an ultimate strength of 55,000 to 60,000 lbs. Anything conforming to these very general specifications has been found to weld satisfactorily, and make excellent tubes.

The steel is rolled to the required gauge in sheets which will square 20 feet long, and is slit into bands 12 inches or 18 inches wide. Theoretically, there would be an advantage in establishing and maintaining a fixed relation between the diameter of pipe and width of skelp, but in practice it has been found wise to use two widths only for the diameters thus far produced. Tubes of 6 inches, 8 inches, and 10 inches diameter are made from skelp 12 inches wide; those from 12 inches to 24 inches diameter are made from skelp 18 inches wide.

As skelp in 20-feet lengths is not long enough to make tubes of the length most convenient for use and economical for shipment, the strips are united by welding the ends together. The machines for this purpose are very simple in construction and operation, and do their work very rapidly. The resulting weld is so smooth as not to be visible in the finished pipe. As the stock is thus prepared by what is known as "cross-welding," it is reeled and passed to the tube machines. By this means the pipe-maker is rendered independent of the limitations of the rolling mills, which, in the gauges demanded, cannot, with present appliances, advantageously roll more than 20-feet lengths. So cheap and rapid is the cross-welding process, however, that it is doubtful if any advantage would be found in having the strips longer. They would be more costly to transport and handle. The fact that, with cross-welded stock, tubes 100 feet long have been made, and that if it was of advantage to do so they could be made 500 or 1000 feet long, shows how little the pipe-maker is dependent upon the rolling mill manager. It is, however, useless to make pipes exceeding in length existing facilities for transportation. Thirty feet is the average car length, and on certain patterns of platform cars, 32 feet can be loaded. To exceed this length would be to increase the difficulties of transportation and handling far more than the value of the couplings saved. The cross-welded stock is passed to the tube machine, and one end is laid on the guide-table, which, being adjustable, is set to the angle due to the width of skelp and the diameter of the pipe to be made. On this table are the feed-rolls, geared together, which draw the stock into the machine and pass it forward. As the skelp enters, it moves across the face of an anvil-horn, which is rounded to conform to the shape of the pipe. The curvature of the stock is effected by the movement of an oscillating jaw, which presses the metal against the face of the anvil. The impetus of the feed-rolls is intermittent, moving the metal forward when the shaping-jaw is raised, and leaving it at rest when pinched between the fixed and moving parts of the shaping mechanism.

The source of heat is a small furnace of cast iron, scarcely more than a cubic foot in dimensions. This furnace is lined with refractory material, having passages of such shape as to deflect the gas and blast where they are needed. The furnace contains two or more blow-pipes, as may be required. The fuel is a gas of a quality never before employed in any metallurgical operation. It is composed, as nearly as may be, of equal parts of hydrogen and carbonic oxide, is free from carbonic acid and sulphur compounds, and has a flame temperature of 3800° Fahr. It is delivered to the machines under a considerable pressure, and mingles with the requisite volume of blast at the point of ignition. The practice in burning the gas, as in making it, is different from that followed anywhere else, so far as I am aware, but it has been found to be the one best adapted to the special requirements of the industry.

Heating and welding are, of course, the only elements of the process involving any particular difficulty. The nature of this problem can be judged from the fact that it required more than two years of very costly and anxious experimentation, in directions in which previous experience furnished no guide. To pass cold steel into a flame in which irridium will fuse, bring it from atmospheric temperature to that of welding in about five seconds, weld it and quench it with water at once, without burning the metal or producing any appreciable scale, is a metallurgical operation of great delicacy, and one which demands that all the conditions shall be right. If the flame assumes an oxidizing character for an instant, the weld is missed; if the stock binds, the feed slips, or for any other reason the steel remains in the heat an instant longer than is needed, it will run as fluid as water and make a hole in the pipe. When I say that a confident operator, who understands the conditions under which he is working, will often leave his machine and attend to something else while it is making pipe at the rate of 18 to 24 inches per minute, the perfection of the machine and process will be appreciated. It is not, however, so automatic that the operator can leave his machine with entire safety. With a constant pressure of air and gas, it would only need to be started right to finish a pipe without further attention. But as machines are started and stopped, producing slight variations in the engine speed, and for other causes the pressure of air and gas varies, the operator needs to increase or diminish the speed of his feed. This is accomplished by a modification of the link motion, which enables him, while the machine is running, to stop the feed altogether, or increase it so that it shall drive the skelp forward at the rate of more than 200 inches a minute. The average running speed in pipe making advances the skelp from 90 to 100 inches per minute. I have no doubt that further improvements in the plant will make the process so nearly automatic that, after the operator has run out a foot or two, he need give his machine no further attention.

It is essential that the gas and blast should be as perfectly under control as the feed. There are always two edges to be equally heated—one at the end of the already formed pipe, and the other the edge of the flat or entering skelp which is about to be added on. For this reason the operator must be able to vary the proportions of gas and blast in each blow-pipe. This he can do without leaving his position or abandoning the lever by which he controls the feed mechanism. The direction of present experiment is to make the pressure of gas and air so constant that the operator, having ascertained the proper rate of feed, can let one reel of skelp follow another with no concern for his product unless something breaks.

The machine having these complex functions of feeding, heating, welding, and discharging the pipe, is quite simple in construction, and has but few working parts. It is of unusual interest to see cold skelp drawn in, heated, shaped, welded, and passed out as finished pipe, at the rate of a foot to two feet per minute, with all the operations by which flat steel is converted into pipe, performed within a space which could be covered by one's hat. I venture to say it is wholly unlike any industrial process to be seen in this or any other country.

The welding is done under a light hammer, which strikes about 320 blows per minute. The hammer is so arranged as to give what is known as a dead blow. The weld thus secured is vastly superior to that attainable by the pressure of rolls. A hammer blow can be delivered at the mouth of the furnace, and does not rob the metal of the heat necessary to produce a perfect union. Pipe can be made without the hammer, by the contact of the jaws which bend and form it, but the hammer is more certain. The welds produced by hammering are as perfect as are ever made on the anvil by a skilled blacksmith. Test pieces subjected to tension show that the metal tears before the weld separates. As the direction of the weld is such that, under pressure, it is never subjected to a strain tending to open it, it serves as a spiral reinforcement, and pipes made by this method, unless they show a leak in the initial test, can be depended upon to develop a strength equal to the ultimate strength of the metal composing them. The spirally-welded pipe is an illustration of the best constructive use of material known in the arts. It is, in fact, stronger than a seamless drawn steel tube of the same diameter and thickness of wall.

The weight of steel used in making spirally-welded tubes ranges from No. 14 to No. 6 B.W.G. The diameters now made include all sizes from 6 inches to 24 inches, and will probably be extended to include smaller and larger sizes. The limit in small diameters is that which will admit an anvil-horn stout enough to withstand the heat and hammering to which it is subjected, and remain rigid under the compression of the shaping-jaw. There is no limit in the direction of large diameters except such as is imposed by the present difficulty of obtaining stock of suitable widths and lengths, and the cost of transporting large and light cylinders. When the demand for pressure tubes of larger diameter than 24 inches shall justify provision for their manufacture, there will be no difficulty in making them.

After the pipes leave the machines the ends are squared on a trimming machine, and they are tested in the usual way. They are then provided with their couplings, and are finished by dipping in a bath of Trinidad asphalt. The coating is hard, insoluble, and extremely tenacious, and as a protection against rust is very durable.

This industry has scarcely been established long enough to have a history, but it has experienced a very rapid development. Its product has gone into every use for which pipes of diameters of 6 inches and upwards are employed. They are in successful use as steam and compressed-air conduits, gas mains, water pipes, petroleum lines, and to some extent in architectural and engineering constructions. In mining operations they have met every requirement of service—the saving in transportation charges often amounting, at remote and inaccessible points, to a very large item. They have also been found useful for many purposes for which timber has hitherto been employed—as in trestles, tramway trusses, supporting columns, &c. A 12-inch tube, 30 feet long, with couplings, which would be safe under a working pressure of 500 to 700 lbs. per square inch, will weigh, according to the thickness of metal used and the coupling provided, from 475 to 490 lbs. Thirty feet of lap-welded tube, 12 inches in diameter, will weigh not less than 1700 lbs., and 30 feet of 12-inch cast iron pipe, strong enough to carry a working pressure due to a head of 100 feet, and lighter than that usually demanded in water-works construction, will weigh from 2700 to 3000 lbs., and perhaps more. The spirally-welded steel tube certainly has a range of utility greater than that of any tube previously known, and it places at the command of the engineer a material which broadens his field of operations in all directions, and renders practicable undertakings of great magnitude which have hitherto seemed impossible on the score of cost.

For purposes of comparison I append two tables of interest, showing the strength of spirally-welded steel tubes, and the comparative weights of spirally-welded steel, lap-welded wrought iron, and cast iron pipes:—

Table showing the Proof Strength (elastic limit), and Ultimate Strength of Spirally-welded Steel Tubes.

Diameter of Pipe.	Grade.	Proof Strength per Sq. In.	Ultimate Strength per Sq. In.
Inches.			
6	Standard	866	1408
	Heavy	1106	1798
8	Standard	650	1056
	Heavy	830	1349
10	Standard	664	1079
	Heavy	872	1417
12	Standard	553	899
	Heavy	727	1181
	Extra heavy	893	1451
14	Standard	474	771
	Heavy	623	1012
	Extra heavy	765	1244
16	Light	415	674
	Standard	545	886
	Heavy	670	1088
	Extra heavy	825	1341
18	Light	369	599
	Standard	484	787
	Heavy	596	968
	Extra heavy	733	1192
20	Light	332	539
	Standard	436	709
	Heavy	536	871
	Extra heavy	660	1073
22	Light	302	490
	Standard	396	644
	Heavy	487	791
	Extra heavy	600	975
24	Light	277	449
	Standard	363	590
	Heavy	446	726
	Extra heavy	550	894

Table of Approximate Weights of Spirally-Welded Steel, Lap-Welded Iron, and Cast Iron Tubes.

SPIRALLY-WELDED STEEL.				
Diameter of Pipe.	Light.	Standard.	Heavy.	Extra Heavy.
Inches.	Lbs.	Lbs.	Lbs.	Lbs.
6	...	4·66	5·87	...
8	...	6·22	7·88	...
10	...	9·84	12·83	...
12	...	11·81	15·41	18·89
14	..	14·27	18·47	22·54
16	17·33	21·53	26·19	31·89
18	18·71	24·21	29·34	35·76
20	20·68	26·37	32·25	39·63
22	22·60	29·30	35·58	43·43
24	24·61	31·89	38·73	47·36

LAP-WELDED IRON.		CAST IRON.		
Diameter of Pipe.	Standard.	½" Thick.	⅝" Thick.	¾" Thick.
Inches.				
6	18·77	31·82	40·56	49·6
8	28·35	41·64	52·68	64·27
10	40·64	51·46	65·08	78·99
12	54·65	61·26	77·36	93·7
14	57·89	71·07	89·61	108·46
16	70·00	80·87	101·82	123·14
		⅝" Thick.	¾" Thick.	⅞" Thick.
18	...	114·1	137·84	161·9
20	...	126·33	152·53	179·2
22	...	138·6	167·24	196·46
24	...	150·85	181·92	213·28

ON

THE INSPECTION OF MATERIALS OF CONSTRUCTION IN THE UNITED STATES.

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THE great advantage to be gained by a careful inspection of all materials used in construction, in regard to safety and permanency, and to accuracy of workmanship, has been longer recognised in Great Britain and on the Continent than in America. This is probably owing to the way in which great enterprises have been "rushed" in the United States. Time, in too many instances, has been considered of more importance than absolute safety and durability; the structure being afterwards strengthened if found necessary.

This has been most noticeable in railroads built through "new" country, where the object in view has been to reach the terminal point and get to work. These "loose" methods are now being very largely done away with, and a large proportion of the structures lately built are not only carefully inspected during the process of manufacture of the iron or steel, but also during the working and assembling at the bridge shop, and while the erection is going on; the manufacturers, in many cases, by the terms of the specifications, not being relieved from the chance of rejection until the final acceptance of the finished structure after erection. The reasons calling for this increased care in inspection, such as increase of traffic and rolling loads on railroads, heavier and more substantial buildings, &c., have been so thoroughly discussed before the different engineering societies that it is unnecessary to take them up here, the object of this paper being to show the different requirements that iron and steel makers in America are called upon to meet, and which British and Continental makers have as well occasionally been called upon to fulfil for American orders.

The practice of having structural material inspected has increased a great deal within the last few years in the United

States, until at present the very largest share of all structural materials for bridges, boilers, or buildings is now ordered subject to inspection, and there are several firms who make the inspection of iron and steel a specialty. Formerly a great many railroad companies, when they required any inspection at all, sent out some of their office force, frequently young men with absolutely no knowledge of iron and steel whatever, men who could not explain the terms of the specifications under which they were expected to work. Their inspection was on a par with their ignorance, and consisted principally in making trouble for the mills. A great many railroad companies now maintain a regular corps of inspectors, who are under the direct supervision of the chief engineer, the general superintendent, or the superintendent of bridges and buildings. Of the private inspecting firms, the successful ones are mainly those whose members have served their apprenticeship either in iron and steel works or at the large bridge works; and as they have their own men constantly located at all of the principal structural and rail mills, most of the railroad companies find it more economical and convenient to employ them. Being constantly at the mills, they also become more thoroughly acquainted with individual peculiarities at the various locations, and can thus work with less friction. Several of the larger works have provided offices exclusively for the inspectors, where there are desks at which they can do their clerical work, and, if permanently located at the works, keep their orders and report books locked up.

The growth of inspection has also necessitated the use of accurate and rapid means of measuring and calculating, so that all well-equipped testing-rooms are now provided with standard micrometer gauges, calipers, and steel rules, tables of diameters and areas, frequently tabulated in such a way that the percentage of reduction of area can be read at a glance. Another almost universal equipment is the "Thacher Slide Rule," which probably most of the members are familiar with, as it was fully described in a paper read some years ago before the British Association for the Advancement of Science, by Mr. W. F. Stanley.

As regards the requirements of testing, there is a growing tendency among engineers towards uniformity, largely brought about by the publication of "Standard Specifications" by such well-known engineers as Theo. Cooper, C. C. Schneider, J. A. L. Waddell, and others; Mr. Cooper's Specifications, in particular, having been adopted by a great many railroad companies, and by County Commissioners for highway work.

The general specifications given below are an average compiled from those mentioned above, and from the specifications of some of the largest railroads, all strains being referred to in terms of pounds per square inch, instead of tons per square inch, as the former has become the universal custom in the United States.

General Specifications.

Complete facilities for inspection of material and workmanship must be given by the contractor, and specimens for testing, and the necessary labour, shall be furnished by him, without charge.

The acceptance of any materials or manufactured members by the inspector shall not prevent their subsequent rejection, if found defective after delivery, and any rejected material shall be replaced by, and at the expense of, the contractor.

Material to be tested shall be of full-sized section wherever practicable, or in bars or strips of at least 0·50 square inch in sectional area, and, where possible, should be at least 18 inches long, and have two opposite sides left as they came from the rolls. Test-pieces should not be cut from short crop ends, as they almost invariably contain flaws that cause erroneous results.

A duplicate specimen of each bar or strip to be tested, except in the case of full-sized bars or members, shall be bent cold until it commences to rupture, or through an angle of 180° around a cylinder having a diameter specified for each kind of material, or until the sides are in contact. The bending must stop at the first indication of fracture.

Test specimens must not be annealed, heated, hammered, forged, or otherwise treated, except where specified in the contract; but shall fairly represent the quality of material to be tested.

The testing-machine used by the contractor shall be compared with a standard testing-machine, and if the results vary, the contractor's machine shall be corrected until the tests show that the machines accord.

Wherever full-sized wrought-iron eye-bars are tested, the material shall be allowed a reduction of 1000 lbs. in ultimate strength, and of 2 per cent. in reduction of area, for each additional inch of sectional area over $4\frac{1}{2}$ square inches, down to a minimum of 46,000 lbs. per square inch, and 15 per cent. in reduction of area. Such bars shall have an elongation of 10 per cent. in their whole length when the sectional area is under $4\frac{1}{2}$ square inches, and of 8 per cent. when the sectional area is over $4\frac{1}{2}$ square inches.

In the selection of eye-bars or tension-rods for full-sized tests to destruction, the inspector shall select from fairly representative bars of the whole lot, and shall cause to be made under his personal supervision, three eye-bars or rods of each size and lot to be tested; from these bars he shall select one for test. All of the test-bars must be made in the same way as the lot which they are to represent.

If the full-sized tests are satisfactory, the bars shall be paid for at the contract price, less their scrap value, by the owners of the bridge or parties ordering the tests to be made. If they do not stand the specified tests, they will be considered rejected material, and will be solely at the cost of the contractor.

Specifications for Wrought Iron.

All wrought iron shall have an elastic limit of not less than 25,000 lbs. per square inch, and must be tough, fibrous and uniform in character, neutral in quality and completely welded in rolling, and must have a workmanlike finish. It must be free from injurious seams, especially such as run across the fibre, and must have no blisters, buckles, cinder spots, rough or imperfect edges, or deep creases from tool or roll-guide marks.

The finished iron must be straight, and out of wind, and must not have over 3 per cent. of variation between the actual and the estimated weights.

All wrought iron when nicked and broken at a temperature of over 50° Fahr., or when pulled apart in testing-machines, must show a clean fibrous structure, except in the case of the webs of shape iron, which may be allowed to exhibit as much as 30 per cent. crystalline in the fracture.

The finished iron must show no evidence of butt-welds, and the piles for the wide bars must have the top and bottom covers, and for bars of over one inch in thickness, at least one other bar in the centre of the pile double-rolled and extending over the entire length and width of the pile. Wherever bars of less width than the entire pile are used, the joints shall be well broken in the piling. Material cut too close to the crop ends will not be accepted.

All wrought iron used in tension, except wide plates, shall be made from "double" or "single" rolled iron piling pieces.

Wide plates may, and preferably should, have a few alternate layers of muck bar laid crosswise and extending completely across the pile.

Wherever single-rolled iron and iron made from piling scrap, or from re-rolling old rails, is to be used, the items in which it will be permissible shall be individually specified in the contract.

Specifications for Tension Iron.

All material subject to alternate compression and tension stress shall be considered as in tension.

All iron must come up to the requirements expressed in the following table, in test specimens cut from the finished material:—

Kind of Material.	Tensile Tests.				Cold Bending Tests.	
	Limit of Elasticity per sq. inch.	Ultimate Strength per sq. inch.	Per Cent. Elongation in 8 ins.	Reduction per cent. at Fracture.	Angle of Bend.	Diameter of Cylinder around which the Specimen is to be bent.
Bar Iron.						
Round bars up to 1½ in. diameter .	26,000	50,000	18	25	180°	Upon itself until sides come in contact.
Round bars up to 2⅜ in. diameter .	26,000	50,000	15	20	160°	One diameter of bar.
Square bars up to 1½ in. per side .	26,000	50,000	18	25	180°	Upon itself until sides come in contact.
Square bars of less than 4½ sq. in. sec. area . . .	26,000	50,000	15	20	180°	Diameter equal to the sides of bar.
Flat bars of less than 4½ sq. in. sec. area	26,000	50,000	15	20	180°	Diameter equal to 2 times the thickness.
Bars of more than 4½ sq. in. sec. area	26,000	50,000	12	18	140°	Two diameters of bar.
Channels and Beams.						
Test from web . .	26,000	47,000	12	18	140°	Diam. equal to thickness of specimen.
Test from flange .	26,000	49,000	15	20	160°	Do.
Angle iron . . .	26,000	49,000	13	20	140°	Do.
Other shape iron .	26,000	48,000	14	18	120°	Do.
Plate Iron.—Tests to be taken with the fibre.						
Under 18 inches wide	26,000	50,000	15	20	160°	Diameter twice thickness.
18 to 36 inches wide .	26,000	48,000	12	16	100°	Do.
36 to 54 inches wide .	25,000	46,000	10	10	90°	Do.
Over 54 inches wide .	25,000	46,000	8	8	90°	Do.

Earlier specifications made a difference in the requirements between materials to be used in compression and in tension with the intention of ordering for compression members, in the case of iron, a poorer quality, not as high in tensile strength and ductility, and in the case of steel, a harder material, much higher in tensile strength and with considerably less ductility, than for tension steel. The great difficulty, however, in keeping these various grades separate, and the serious error of having the mills furnishing one class of material to be used in the place of the other, has occasioned the abandonment, by most engineers, of the differing requirements for tension and compression members. However, some engineers of late have been ordering three grades of steel, which can readily be kept separate by being ordered in different ways, namely, the material for the trusses of the highest ductility and tensile strength, the latter ordinarily running from 65,000 pounds to 75,000 pounds; the material for the floor system of medium steel of greater ductility and of lower tensile strength, from 60,000 to 70,000 pounds; and for rivet steel, material of not over 60,000 pounds tensile strength. The great majority of specifications in the United States, however, only require two grades of steel, that for the main members of the structure being all of one kind, the only exception being the softer steel used for rivet rods.

Specifications for Rivet Iron.

Rivet iron shall be subject to the same requirements as tension iron of the same section, and shall further be capable, without cracking or serious abrasion, of being heated to a good forging heat, and made up either by machine or hand work into rivets, and of again being heated to a good red heat, forged as in riveting, allowed to cool, and upon being nicked and cut out of the work, must show good, tough, fibrous structure, without any crystalline appearance. Rivet iron shall especially be required to be neutral in character and tough in fibre *after being riveted,* and to flow well in riveting.

Specifications for Cast Iron.

All cast iron used in compression must be of best quality—tough grey iron—and must be able, in bars of 1 inch square and 5 feet length, and when supported by knife edges 4 feet 6 inches apart, to carry a load of 500 pounds applied at the centre without rupture, and without a deflection of more than 2 inches.

The specifications above stated give substantially all of the requirements in regard to iron, excepting that some engineers permit the use of a little steel scrap in piling, while others will condemn material showing the slightest indication of steel having been used. The use of steel will require much more elaboration, owing to the different requirements of engineers, some merely specifying "steel" with certain physical requirements, while others prescribe the chemical requirements and the method of manufacture as well, making the specifications very rigid and difficult of fulfilment; in fact, some of the recent specifications have been so "stiff" that the manufacturers have thrown up the contract after getting started.

Specifications for Steel.

The method of manufacture of the steel, whether by the Bessemer, open-hearth, or crucible processes, shall be distinctly specified in the contract for each item of material.

Each ingot designed to be used in the contract shall be plainly marked with the blow or heat number in the case of Bessemer or open-hearth steel, and afterwards this heat or blow number shall be stamped upon each piece of finished material rolled from it, and a portion or the whole of one full-sized ingot, from each heat or blow to be used, shall be rolled into a test-bar ¾ inch in diameter. The method of obtaining the ¾-inch round test-bar shall be the same with all of the heats or blows tested, and shall represent in the ¾-inch round the amount of work in the finished product as far as is practicable.

These bars are to be truly round and finished at a uniform dark orange heat, arranged to cool uniformly and without any danger of hardening, from cool draughts of air, being laid on damp ground, or the like, and if any of these bars prove unsatisfactory in tests, the whole blow or heat represented by such defective bars shall be rejected.

Each heat or blow of steel to be used shall be tested first in the ¾-inch round test-bar, both in tensile and bending tests required, and afterwards in specimens to be cut from the finished material; provided that the number of such tests shall not be over four in all for each melt or blow, including the test in ¾-inch round.

The tests first made on the ¾-inch test-bars must exactly conform to the requirements of the specifications. The tensile tests made from the finished steel will be accepted if they give results within 4 per cent. of the requirements of the specifications.

If drillings taken from any portion of the finished material, or from the ¾-inch round test-bars do not satisfactorily answer the chemical requirements of the specifications, the whole charge or blow is to be rejected, unless it shall be proved that the defect was caused by the particular ingot or bloom having been "burned" in heating.

No steel shall be used for structural purposes which contains over 0·08 per cent. phosphorus, and the average percentage of phosphorus of the steel of any given structure, or on any given order, shall not exceed 0·07 per cent.

No steel shall be struck with a hammer or worked while at a black heat.

A variation in cross-section or weight of rolled material of more than 3 per cent. from that specified, may be cause for rejection.

Finished bars must be free from injurious flaws and cracks, and must have a workmanlike finish.

Test specimens shall bend through an angle of 180 degrees, and close down upon themselves without showing a crack or flaw, and similar bars shall have an ultimate strength of from 58,000 pounds to 68,000 pounds per square inch, and an elastic limit of not less than 36,000 pounds per square inch. Tensile test specimens shall elongate at least 23 per cent. in 8 inches, and show a reduction of area of at least 42 per cent.

Test-pieces shall be of at least $\frac{1}{2}$ square inch sectional area, and cut lengthwise from finished bars or shapes, or either crosswise or lengthwise from plates.

All steel eye-bars must be annealed in a properly constructed furnace, and all eye-bars must show the same degree of tenacity and ductility, proportioned to the size of the bar and different manner of testing, that the steel from the same blow or melt did in the various specimen tests on which it was accepted at the rolling-mill.

Specifications for Rivet Steel.

All rivet steel shall be subject to the general specifications given above, and shall further be capable, without cracking or serious abrasion, of being heated to a good forging heat, and made up either by machine or hand work into rivets, and of again being heated to a good red heat, and forged or pressed as in riveting, and allowed to cool; and upon being nicked and cut out of the work it is in, must show a good, tough, silky structure with no crystalline appearance. Rivet steel especially shall be neutral in character and pure in composition, and shall flow well in riveting.

Rivet steel should not have over 0·15 per cent. carbon, and must not have an ultimate strength of over 60,000 pounds per square inch, and must have an elongation of at least 25 per cent. in 8 inches.

Steel rivets should not be heated above an orange colour, much less than the heat put upon iron rivets, which are heated nearly to a lemon colour, often without apparent injury.

Government engineers and many other engineers are requiring that rivet-rods shall be bundled in lots of a ton weight; that the steel of each melt shall be kept separate, and have a metal tag securely fastened to each bundle, with the melt number of the steel stamped upon it—this in lieu of each rod being stamped with the melt number, as with bars of larger section.

Rarely have specifications for steel demanded the tests of the modulus of elasticity (although many engineers have asked for these tests, as a matter of record), as it has been found by practice that the modulus of elasticity varies but slightly for very considerable differences in the quality of structural steel—that is, steel from 55,000 to 80,000 pounds tensile strength runs very closely alike in modulus of elasticity, and can be safely estimated as 30,000,000, whether the steel is made by the open-hearth or the Bessemer acid or basic processes.

In addition to the unannealed specimens cut from the finished material, it is becoming a widely established practice to require a certain number of annealed specimens of the finished materials to be pulled. This, especially, is required with eye-bar material, to prevent the acceptance of material which would be too soft fairly to fulfil the requirements of the specification, but which by cold-rolling—that is, allowing the finishing passes to be made on the metal at a very dark red-heat—will show a considerable increase in tensile strength, the metal being hardened thereby so far as readily to answer the requirements of the specifications. At the same time, when such bars are sent to the bridge shops, and made into eye-bars, and thereafter carefully annealed, according to the requirements of all bridge specifications, and pulled in the testing-machine, the results will be found to fall far below the specifications, and what should be expected of the material from the tensile tests of the finished material. By having a certain number of specimens cut from the full-sized bar, and annealed, this practice on the part of the mills is prevented.

Whenever a test specimen does not fairly represent the average lot of the material, it is the practice of most inspectors to allow a second test to be made, if, owing to flaws, the first test is manifestly not fair. This is frequently occasioned by cutting the test specimen from the ends of bars which have been cut too close to the crop end. In such cases the second finished material test-pieces are taken by cutting actually into the centre of bars to be furnished for the work, thus ensuring that the test-pieces are average specimens.

The requirement for maximum content of phosphorus allowed in material has been specified differently for steel manufactured by the various methods, the highest maximum, from 0·08 per cent. to 0·10 per cent., being allowed in acid open-hearth steel. Most engineers now require the maximum in all cases to be less than 0·08 per cent., and for Bessemer steel not over 0·05 per cent. of phosphorus. Some engineers require the average of Bessemer steel to be less than 0·04 per cent., claiming that only Bessemer steel of this degree of purity can at all equal in uniformity open-hearth steel. For basic open-hearth steel the requirements still vary, and basic steel has not been in use long enough to have the practice settled as to what should be the requirements of the specification. We believe, however, that the limit will be placed at 0·04 per cent. for basic open-hearth steel. Our experience so far with basic open-hearth steel for structural purposes has been that when the carbon runs down to 0·15 per cent., if the basic operation has been successfully carried out in the melting furnace, the percentage of phosphorus will be below 0·04 per cent., and that if the content of phosphorus is above this, it is liable to be non-homogeneous, and the steel is liable to show unsatisfactory results under tensile tests; and this is an evidence that either the slag was not completely basic during the melting operation, or that the temperature in the open-hearth furnace was unsatisfactory, and the working irregular, since in the contrary case the phosphorus would have been reduced below 0·04 per cent. before the carbon had been reduced to 0·15 per cent.

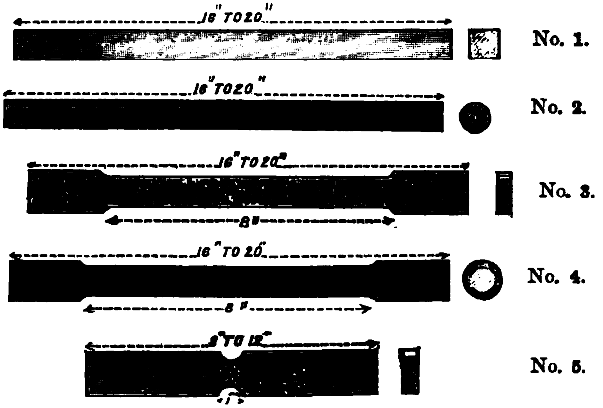
Many engineers have inserted in the requirements of the specifications that the contractors, in placing their bids, shall specify the maximum and minimum limits through which the carbon and manganese shall vary in the steel to be furnished, and also the maximum limit of the sulphur, phosphorus, and silicon.

A large amount of the steel which is now sold subject to specifications has accompanying the invoice a chemical report of the percentage of carbon, manganese, and phosphorus of each melt used in the shipment, which report is furnished by the manufacturer. These analyses are certified by the chemist of the works. Many engineers require, in addition to this, reports of check analyses, made by inspectors or chemists to be selected by them, of one sample from each five or ten melts.

Test-Pieces.

The cut below shows the standard shapes of specimens for tensile tests of both iron and steel.

SHAPES OF SPECIMENS FOR TENSILE TESTS.



No. 1.—Square or flat bar, as rolled.
No. 2.—Round bar, as rolled.
No. 3.—Standard shape for flats or squares, edges smooth and true, fillets ½ inch radius.
No. 4.—Standard shape for rounds.
No. 5.—Government shape for marine boiler plates only. Not recommended for other tests, as results obtained by this shape are generally in error.

Some of the railroads adopt test-pieces of 2, 3, 4, and 5 inches between the shoulders, but the majority are now coming round to the above standard shapes, as drawn by Wm. Kent, M.E., some years ago, and since adopted and recommended by R. H. Thurston, M.A., in his "Materials of Engineering," and by several other writers on the testing of iron and steel. The sizes recommended by Wm. Kent are:

For tool steel $\frac{11}{16}$ inch diameter (1·75 centimeter), or $\frac{3}{8}$ square inch (2·44 square centimeters) area; in other metals, either $\frac{3}{4}$ inch (1·9 centimeter) diameter, or 0·44 square inch (2·84 square centimeters) area.

These sizes are adapted to a 50,000-pound testing-machine, which is the size of machine most commonly used in the United States, although mills putting in new machines are largely adopting the 100,000 or 200,000-pound sizes.

The form of test-pieces generally adopted in testing iron at the mills is the parallel-side strip about 16 to 20 inches long, as it is found to give satisfactory results, and is much cheaper to prepare than the turned section. Of course, large squares and rounds have to be turned down, and it is found that in so doing the best and strongest part of the metal is turned off, and only the weak centre left—a point which we do not think is recognised so generally as it should be, as frequently iron which in full-size section would show 45,000 to 48,000 pounds, runs down to 43,000 to 45,000 pounds in the turned section. For this reason, we request in our own specifications, that when possible "two opposite sides of the test-piece should be left as they came from the rolls."

One advantage in the straight-side test-piece is that, no matter where it breaks, the elongation in 8 inches can be taken; while in a turned specimen, 8 inches between the shoulders, if it breaks at the fillet, there is no way of measuring elongation, and the record is incomplete.

It has become a very general practice among engineers, in specifying the quality of steel to be used, to require a preliminary test of the material, the test-piece for which shall be of such a size as fairly to represent the amount of work done on the finished material. This test-piece is taken in the same manner in all cases, being cast directly from the ladle into a small ingot 4 inches square and 1 foot long, usually when the ladle is about half emptied. These test ingots are then treated as nearly as possible in a uniform manner as regards the time of reheating, rolling, and allowing to cool, special care being observed in this last step that there may be no tempering caused by the bars being exposed to draughts of cold air, or from being laid on damp or wet places. At a great many mills troughs are placed near the rolls, filled with dry sand, on which the bars are laid to cool.

With these precautions, the test specimens are supposed, in each case, fairly to represent the quality of the material; and the requirements of the specifications are, that the steel of these preliminary test-bars shall exactly answer the specifications, further provision being made that tests of the steel of each melt shall be made on bars cut from each largely varying section into which the steel of each melt is rolled, an allowance being made in many cases of 4 per cent. In some specifications the amount of variation is left to the discretion of the inspector, with the statement—"A reasonable allowance shall be made in these tests taken from the finished material for the variation in section."

The intention of the engineers who draw up their specifications in this way is to obtain for their structures steel as closely as possible *uniform in its chemical composition, and uniform under tests made under like conditions.*

The specifications usually state that the steel shall be cast into test-ingots of 4 inches square, of a length of about 1 foot, and that the test-ingot shall be cast in a mould as uniformly as possible in method, when about one-half of the metal has been cast out of the ladle, the ingots to be rolled usually upon a 9-inch mill to bars of $\frac{3}{4}$-inch round. This test is usually spoken of in America as the "preliminary $\frac{3}{4}$-inch round test."

This system of requiring a "preliminary $\frac{3}{4}$-inch round test" from which the original selection of the material will be made has been objected to by many of the large contractors and steel manufacturers. They claim that the $\frac{3}{4}$-inch round test does not fairly represent the quality of the material, in that a small 4-inch square ingot is a very difficult ingot to obtain sound, and that flaws are therefore very apt to occur in the $\frac{3}{4}$-inch round test specimens.

This, however, has not been our experience, and this statement we make from a very large experience with the $\frac{3}{4}$-inch round test. Our records show no more flaws in the $\frac{3}{4}$-inch round tests than in the tests cut from the finished material. Of course, where such flaws do exist, second or further specimens are pulled, until a sound specimen is obtained. Again, this objection seems to us to be begging the main question, which is as to the advisability of a uniform preliminary test, and not as to whether the test-ingot for this test should be cast in a 4-inch ingot mould, or in a larger mould for the sake of securing a sounder ingot.

A further objection is that these ¾-inch round test-pieces are very liable to be cold-rolled, or to be hardened by too rapid cooling.

This argument, it seems to us, is one that only refers to careless work. If proper precautions are taken to have these ¾-inch round test-pieces rolled, and afterwards cooled uniformly, they can, we believe, be obtained much more uniform than the average of test-pieces cut from the finished material.

The argument of the extra expense of the ¾-inch round test does not seem to us to be valid, if the advantages to be obtained from it are taken into consideration, as the test is one readily obtained at nearly all of the large steel plants; and the bulk of the test-rods can be used for rivet steel, or for other purposes for which the steel has a ready sale.

The real question at issue with reference to the preliminary ¾-inch round test seems to us to be *whether it is advisable to have the steel for any structure uniform chemically or uniform physically*—that is, whether plates and angles of ⅜-inch thickness, rolled from ingots of the same size, as thick eye-bars of 1½-inch to 2½-inch thickness ordinarily are, shall be made from the same quality of steel, and accept the variation in tests due to the variation in work upon the different sections, or whether the thicker sections shall be made of higher carbon steel, which will answer the same tensile requirements in the 1½-inch to 2½-inch thick bars that the softer lower carbon steel does in the ⅜-inch thick bars. In the one case the steel for the structure would be practically homogeneous chemically if the steel were accepted upon a preliminary uniform method of testing; and, in the other case, steel in a given structure would be non-homogeneous, much harder, and have a considerably higher percentage of carbon in the thick sections than in the thin.

At present the majority of engineers, we believe, require uniform steel chemically, and the preliminary test is, we believe, the "fashion," although the question is no doubt a moot one, and deserves careful consideration. From a comparison of several thousand tests of both acid open-hearth and acid Bessemer steel, selected from the records of tests, made by us, of American structural steel for bridges, which we have inspected, the steel tested being as fairly representative as possible of steels ranging from 65,000 to 75,000 pounds tensile strength per square inch, we found the following average variations between the ¾-inch round test and the test of the finished material:—

Plates, Angles, Channels, and Beams.

	Per Cent.			
Elastic limit, . .	5·15	lower in finished	material test	than in ¾-in. round test.
Tensile strength, .	1·11	,,	,,	,,
Elongation in 8-in.,	5.76	,,	,,	,,
Reduction of area,	7·18	,,	,,	,,

Tension Bars.

	Per Cent.			
Elastic limit, . .	5·08	lower in finished	material test	than in ¾-in. round test.
Tensile strength, .	3·07	,,	,,	,,
Elongation in 8-in.,	5·63	,,	,,	,,
Reduction of area,	10·58	,,	,,	,,

In getting these averages, 4,300 tests were actually tabulated, and fully as many more were roughly compared. The steel was to fill a specification as follows:—

Elastic limit, at least 38,000 lbs. per square inch.
Tensile strength, from 65,000 to 75,000 lbs. per square inch.
Elongation, at least 18 per cent. in 8 inches.
Reduction of area, at least 35 per cent.

This particular specification was taken, as the steel was considered to be fairly representative of the average structural steel in use in this country. The average of the ¾-inch round tests was as follows:—

Elastic limit, 42,580 lbs. per square inch.
Tensile strength, 69,625 lbs. per square inch.
Elongation, 25·95 per cent. in 8 inches.
Reduction of area, 52·85 per cent.

The plates, angles, and channels gave the following average:—

Elastic limit, 40,390 lbs. per square inch.
Tensile strength, 68,850 lbs. per square inch.
Elongation, 24·44 per cent. in 8 inches.
Reduction of area, 49·56 per cent.

Bars ranging from 4 inches by ½ inch to 8 inches by 2½ inches, gave the following average:—

Elastic limit, 40,420 lbs. per square inch.
Tensile strength, 67,480 lbs per square inch.
Elongation, 24·46 per cent. in 8 inches.
Reduction of area, 47·25 per cent.

One engineer states, in all of his recent specifications, that "steel may be made by the open-hearth or by the Bessemer process, but no steel shall be made at works which have not been in successful operation for at least one year;" and "steel made by the Clapp-Griffiths process will not be accepted."

He, however, gives his preference to open-hearth steel, and in his latest specifications, published this last summer, in giving the chemical requirements, says that Bessemer steel must in no case exceed 0·05 per cent. phosphorus, and that the average must not exceed 0·04 per cent.; while in open-hearth steel he allows individual heats to run up as high as 0·10 per cent., and gives 0·08 per cent. as the average.

To show the changes in requirements that have taken place during the last ten years, we quote from six specifications drawn by the same engineer, which have been considered "standard," and frequently referred to by engineers who have not regular specifications of their own.

1st. 1879.—Open-hearth steel for tension members.

Not less than 50,000 lbs. elastic limit.
Not less than 80,000 lbs. tensile strength.
Not less than 12 per cent. elongation in 8 inches.
Not less than 20 per cent. reduction of area.

2nd. 1881.—Open-hearth or Bessemer steel.

Tension Members.

Elastic limit, 40,000 to 45,000 lbs. per square inch.
Tensile strength, 70,000 to 80,000 lbs. per square inch.
Elongation in 8 inches, at least 18 per cent.
Reduction of area, at least 30 per cent.

Compression Members.

Elastic limit, 50,000 to 55,000 lbs. per square inch.
Tensile strength, 80,000 to 90,000 lbs. per square inch.
Elongation in 8 inches, at least 12 per cent.
Reduction of area, at least 20 per cent.

3rd. October 1, 1882.—Steel must be open-hearth.

Tension Members.

Elastic limit, not less than 40,000 lbs. per square inch.
Tensile strength, not less than 70,000 lbs. per square inch.
Elongation in 8 inches, not less than 18 per cent.
Reduction of area, not less than 45 per cent.

Compression Members.

Elastic limit, not less than 50,000 lbs. per square inch.
Tensile strength, not less than 80,000 lbs. per square inch.
Elongation in 8 inches, not less than 15 per cent.
Reduction of area, not less than 35 per cent.

4th. December 1, 1885.—No special method of manufacture specified, but all steel of the same class must be made by the same process.

Tension Members.

Elastic limit, not less than 40,000 lbs. per square inch.
Tensile strength, not less than 70,000 lbs. per square inch.
Elongation in 8 inches, not less than 18 per cent.
Reduction of area, 42 per cent.

Compression Members.

Elastic limit, not less than 50,000 lbs. per square inch.
Tensile strength, not less than 80,000 lbs. per square inch.
Elongation in 8 inches, not less than 15 per cent.
Reduction of area, not less than 35 per cent.

5th. June 15, 1887.—Open-hearth or Bessemer steel must be made at works in successful operation at least one year. Clapp-Griffiths steel will not be accepted.

Phosphorus must in no case exceed 0·10 per cent., and must average 0·08 per cent.

Tension Members.

Elastic limit, not less than 40,000 lbs. per square inch.
Tensile strength, 67,000 to 75,000 lbs. per square inch.
Elongation in 8 inches, at least 20 per cent.
Reduction of area, at least 42 per cent.

6th. Summer of 1888.—Steel to be made as in 5th example above.

Open-hearth steel: Phosphorus not to exceed 0·10 per cent., and must average 0·08 per cent. Bessemer steel: Phosphorus not to exceed 0·05, and must average 0·04 per cent.

Tension Members.

Elastic limit, not less than 38,000 lbs. per square inch.
Tensile strength, 63,000 to 70,000 lbs. per square inch.
Elongation in 8 inches, at least 22 per cent.
Reduction of area, at least 45 per cent.

In specifications Nos. 1, 5, and 6, there is no mention made of compression steel, and it was furnished of the same quality as the tension steel.

The specifications show a tendency to give a decided preference to open-hearth steel, with a gradual lowering of the requirements in tensile strength, and an increase in elongation and reduction of area.

The latest specifications require a drifting test for steel plates, angles, and shapes—a $\frac{3}{4}$-inch hole, punched as in ordinary work for riveting, the centre of the hole being $1\frac{1}{2}$ inches from the edge of the specimen, to withstand the operation of drifting, by blows of a sledge upon a drift pin, to at least $1\frac{1}{2}$-inch diameter without fracture. The advantage of this test is that it can be made very much more cheaply than ordinary tensile tests, or even bending tests, where the sheared edges have to be planed off in order to give the steel a fair opportunity to show its ductility. Many of these tests can be made without much expense on the short crop ends which are necessarily made in cutting the material to length, and the advantage of the many tests in proving the homogeneity of the steel is apparent.

Tempering tests have also been introduced in recent specifications, and steel that has been heated to a dull cherry-red, and quenched in water at 60° to 80° Fahr., according to the different specifications, must bend 180° around a pin varying from 1 to 2 diameters without sign of fracture.

This change has been of great benefit to the travelling public, as it ensures a greatly superior quality of material, in which the chances of failure, due to sudden changes in temperature, or to careless heating and cooling, either at the mill or at the bridge shop, are reduced to a minimum.

The effect of temperature on steel has now become very well known, and needs no discussion here. With iron, however, it is different, and a great variety of opinions exist as to the effects of temperature upon this form of metal, varying from negative to positive.

In a paper read before the Engineers' Society of Western Pennsylvania, at Pittsburgh, Pa., October 18, 1887, by Jos. Ramsey, Jr., chief engineer of the C. H. & D. R. R., a series of tests, showing the effect of temperature ranging from 0° Fahr. to 60° Fahr., was discussed, and the conclusion arrived at was, that the effect of freezing was to decrease the ductility *under impact*, making the iron more crystalline and brittle. This conclusion was combated by several of the members, and other tests were brought forward to show that the effect was so slight as to be practically *nil*. Engineers are, however, pretty well agreed that bending and nicked bending tests should not be made on iron that has been exposed to a temperature below freezing, without first allowing it to become warm, reaching, say, a temperature of about 60° Fahr., or, as the mill men express it, "allow the frost to get out of it."

About two years ago, an instance came under our observation of some 6-inch channels that had been "lying out in the cold" over night, at a temperature of probably 10° to 15° Fahr., which, when struck with a hammer on the web, split up from 6 inches to 18 inches. While subsequent tests on the same channels showed that the material was not strictly first-class, they also showed that the iron, when warmed, developed from 50 to 75 per cent. fibre, whereas the cracked channels were 75 to 100 per cent. crystalline, as was also shown by further nick bending tests made at the cold temperature. Instances of this kind would tend to show a molecular change due to cold, and a change great enough to affect seriously the strength of the iron if exposed to sudden shock at low temperatures, as in the case of the derailment of a train on a bridge.

From a consideration of such facts as these, our inspectors have for the last three or four years been making all bending and nicked bending tests at a temperature of 60° Fahr., unless otherwise directed, proceeding on the assumption that during the greater portion of the year, in this latitude, the temperature is above the freezing-point—the average being 52° Fahr.—and that a uniform temperature is necessary in order to get comparative results of the fibrous quality of wrought iron. We also recommend to engineers that where the iron will be subject to extremely low temperatures, a series of fracture and bending tests should be made at freezing temperatures, and that reasonably ductile results under such treatment should be required.

The effect of temperature upon tensile and compression tests is not at all so marked as it is on tests under impact, for with whatever rapidity the strains have been put upon specimens by tensile or compressive apparatus which can measure the strains applied, the work and flow of the metal has so increased the temperature of the parts as not seriously to modify the results at ordinary temperatures, even though the experimental bars be immersed in freezing mixtures while being tested.

Planing all sheared edges in structural work is being required more and more in this country, and for this purpose many of the larger steel-works are procuring fast rotary planers, but the average structural mill is not equipped as finely as are the large structural mills in Great Britain. This probably is due to the fact that for many purposes we use universal mill plates, and there has not been the necessity for planing so many sheared plates here as abroad.

Steel pins are required to be carefully annealed after being rolled and before being turned up, and pins of over 6 inches in diameter are in most cases drilled through their longer axis with holes from ½-inch to 1½-inch diameter, with the intention of testing the soundness through the entire length. Test specimens for pins are ordinarily cut from the ends of blooms which have been forged into sizes convenient for the purpose.

Numerous instances could be cited to show the unreliability of Bessemer steel for structural purposes. One of the most marked, however, that has come under our notice will suffice.

A 12-inch I-beam weighing 30 pounds to the foot, 20 feet long, which had been rolled of a new section to replace 42-pound iron beams, on being unloaded from a car, broke in two about 6 feet from one end. The Bridge Company wrote about the accident as follows:—

"In unloading the 12-inch beams, one about 20 feet in length, in dropping, broke completely in two, about one-third the distance from one end. There is apparently no defect in the beam at this point, nor anything to account for the breakage. The chemical analysis and tests appear good. We are at a loss to account for the breakage, and it shakes our confidence in the whole subject of steel beams."

The analysis of the test ingot of the Bessemer blow from which the beam was made was as follows:—

	Per Cent.
Carbon	·18
Manganese	·60
Phosphorus	·072

We directed that the broken piece be shipped to us, and on receiving it, found the fracture to be exactly at right angles to the flange and almost as true as if it had been cut in a planer. Although rusty, the fracture appeared to be finely crystalline, and showed no evidence of any flaw which would have caused the break.

Drillings taken from various points in the fractural surface showed:—

		Per Cent.	
No. 1.	Carbon	·18	Flange.
	Manganese	·68	
No. 2.	Carbon	·18	
	Manganese	·67	
No. 3.	Carbon	·18	
	Manganese	·68	
No. 4.	Carbon	·18	Web.
	Manganese	·68	
No. 5.	Carbon	·18	
	Manganese	·67	
No. 6.	Carbon	·17	
	Manganese	·67	
No. 7.	Carbon	·17	Flange.
	Manganese	·69	
No. 8.	Carbon	·17	
	Manganese	·68	
No. 9.	Carbon	·17	
	Manganese	·68	

An average sample of the nine sets of drillings gave:—

Carbon	·18 per cent.
Manganese	·68 ,,
Phosphorus	·09 ,,
Sulphur	·063 ,,

Tensile test of the original ¾-inch round test-bar gave:—

Elastic limit	39,160 lbs. per sq. in.
Tensile strength	68,360 „ „ „
Elongation in 8 inches	29·25 per cent.
Reduction of area	52·86 „
Character of fracture	Silky, cupped.

Of the beam cut as close to the broken end as possible:—

	Flange.	Web.	Flange.
Elastic limit	40,580 lbs. per. sq. in.	45,240 lbs. per sq. in.	41,660 lbs. per sq. in.
Tensile strength	62,140 „ „ „	68,540 „ „ „	64,110 „ „ „
Elongation in 8 inches	23·75 per cent.	23·62 per cent.	27·50 per cent.
Reduction of area	53·38 „ „	56·86 „ „	51·79 „ „
Fracture	Silky.	Silky, cupped.	Silky, pitted.

The analyses and tensile tests made do not show any cause for the failure.

The cold and quench bending tests of both the original ¾-inch round test-pieces, and of pieces cut from the finished material, gave satisfactory results; the cold-bending tests closing down on themselves without sign of fracture.

Numerous other cases of angles and plates that were so hard in places as to break off short in punching, or, what was worse, to break the punches, have come under our observation, and although makers of Bessemer steel claim that this is just as likely to occur in open-hearth as in Bessemer steel, we have, as yet, never seen an instance of failure of this kind in open-hearth steel having such a composition as that given below:—

		Per Cent.
Carbon	below	·25
Manganese	„	·70
Phosphorus		·08

Mr. J. W. Wailes, in a paper read before the Chemical Section of the British Association for the Advancement of Science, in speaking of mysterious failures of steel, states that investigation shows that "these failures occur in steel of one class, viz., soft steel made by the Bessemer process."

Bessemer steel-makers may claim that in a general paper of this kind it is unfair to criticise their process. There is some justice in this, but at the same time it seems proper to state the reasons for the growing tendency among engineers to rule out Bessemer steel for tension members and all of the more important structural purposes. This tendency, we think, is fully as strong in Europe as in America, and the reports of the Secretary of this Institute, and of the Iron and Steel Association of the United States, in their records of the statistical progress of new steel plants and processes, show a most remarkable growth of open-hearth furnace building.

THE IRON DEVELOPMENT AND ORE RESOURCES OF VIRGINIA.

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THE writer approaches this subject with a great deal of diffidence —first, because it is utterly impossible to satisfactorily treat it within the limits of a paper, and, secondly, because the larger development is of so comparatively a recent date as to make authoritative data on some interesting points unavailable.

For over a hundred years small charcoal furnaces have been in existence at widely scattered points, making a few tons of iron daily, and then gradually increasing to a daily output of, say, 10 to 12 tons, as the market widened. With the exhaustion of local supplies of wood, inaccessibility to market, and sharp competition, bringing lower prices, many were compelled from time to time to make temporary stops, and finally to cease altogether. During the first half century there were at different times in operation between seventy-five and ninety charcoal furnaces. The last "Directory of the Iron and Steel Works of the United States" (1890) gives nineteen as the number of charcoal stacks in Virginia. Of these, several are cold, and, it is perfectly safe to say, will never resume. All of them lie within a few miles of the Norfolk and Western and Shenandoah Valley railroads and run on the brown ores of, and adjacent to, the Potsdam sandstones, to be hereafter described. The iron made by these furnaces was almost wholly cold blast, and noted for its excellence for tough casting and chilling car wheel irons. The change came when the completion of the Chesapeake and Ohio Railway made the fine coking coals of West Virginia available, and an extraordinary impetus was given when, in 1882, the Norfolk and Western Railroad, with wise foresight, built to the Flat Top coking coals, and opened up that wonderful field to the outside world.

The census year of 1880 gave the total output of pig iron in Virginia as 17,906 tons.

The census year of 1890, just completed, gives 302,447 tons. Of this, the charcoal production was under 18,000 tons, the balance being made by twelve coke furnaces. The rapid increase in late years is best seen by the figures of the annual production: 1886, 156,250 tons; 1887, 175,751 tons; 1888, 197,306 tons; 1889, 251,356 tons. There are now in course of active construction (and the majority nearing completion) ten large first-class modern coke furnaces, with a yearly capacity of 250,000 gross tons, and several projected.

The important question now arises: What are the sources of ore supply for all of these plants? To settle this, it is necessary to briefly consider existing geological conditions.

Every known character of ore is to be found, in varying quantities, in the State of Virginia.

1. The magnetic, specular, and gossan ores in the older rocks east of the Blue Ridge (Archæn belt).
2. The hydrated brown hæmatite of the Potsdam sandstones and slates, and in the Silurian limestones overlying them (Nos. I. and II. of Professor Rogers).
3. The hydrated brown hæmatite of the Lower Silurian shales (No. III. of Professor Rogers).
4. The anhydrous red hæmatites, or fossil ore, of Professor Rogers' Hudson Epoch No. V., ordinarily known as the Clinton or dyestone ores (Upper Silurian).
5. The hydrated brown hæmatites of the Oriskany Epoch of Professor Rogers, No. VII. (Upper Silurian).
6. The hydrated brown ores accompanying the subcarboniferous limestones of No. XI.
7. The carbonates of the Coal measures, No. XI.

These will be considered in the inverse order.

The carbonates can be dismissed without further notice. As yet they have only been found as nodules in the slates, and are of no commercial value whatever.

Of the subcarboniferous limestone brown ores, but little is known. They are of unusual occurrence, and apparently only local, and on a limited scale. As far as they have been identified, they occur along the line of the great fault in Tazewell County, Virginia, on the Clinch Valley extension of the Norfolk and Western Railroad, by which fault No. XI. is brought into direct contact with No. II. The external indications for many miles would lead the casual observer to believe in the existence of very large bodies of ore, but positive developments weaken this impression. The quality of the ore is very fair, a considerable number of analyses showing:

Iron from 38 per cent. to 49 per cent.
Silica from 13 per cent. to 22 per cent.
Phosphate from 0·13 per cent. to 0·44 per cent.
Manganese from 1 per cent. to 2·40 per cent.

While these ores may serve as a local supply, they can never become, from present knowledge, of commercial value, in Virginia, at least.

No. VII.—We now come to one of the great leading ore deposits of Virginia, which has during the last eight years furnished the largest amount of ore, and which was until within the last year the largest annual ore producer, but which is now being exceeded by the output of the ores of Nos. I. and II. It is commonly and commercially known as the Oriskany brown ore, and supplies the furnaces at Lowmoor, Longdale, Victoria, and Princess.

At the present time these deposits are only reached by the Chesapeake and Ohio Railway. As there seems to be no reason for doubting the existence of the measures carrying these ores for several hundreds of miles through Virginia in a north-east and south-west direction, it is quite within the range of probability that at no distant day the large area carrying these measures, now inaccessible, will be penetrated by new railroads or branches from existing roads, and the output of ore largely stimulated thereby. This is particularly probable from the fact that this ore deposit, in connection with that of No. V. hereafter noted, lies nearer to the great coal-fields than any other. Incidentally it may be stated in passing, that recent developments from Big Stone Gap, Wise County, Virginia, and Middlesborough, Kentucky, positively claim the existence of the Oriskany ore at or near those localities. This being the case, it seems to prove the continuity of this ore deposit over several hundreds of miles. The well-known aphorism, "All is not gold that glitters," is thoroughly applicable not only to this great lead of ore, but to all other brown ores to be hereafter considered. To quote from a recognised anthority, the late Prof. J. L. Campbell, of Washington and Lee University, Lexington, Virginia—"Although the Oriskany is the most important of the ore-bearing formations in this particular region, it must not be inferred that every part of it, or even the greater part of it, is iron ore. Large portions consist of a coarse, grey sandstone, that is frequently highly coloured with iron rust, that breaks up rapidly when exposed, and weathers into round boulders of a brown colour.

In many places gigantic boulders, and even cliffs, 20 to 30 ft. high, outcrop on the mountain-side, and strike the inexperienced observer as iron ore, pure and simple; but oftentimes these masses are fatally charged with silicious matter, and are commercially valueless. Yet these are usually the landmarks which indicate large and valuable deposits of good ore immediately under them. Great variations both in quantity and quality occur in close proximity, even in thoroughly good mining ground, requiring the watchful attention of the practised eye and experienced miner. The usual pitch of the ore can be taken at about 45°, conforming to the general stratification; but this is constantly changing, at times flattening out, and at other times nearly vertical.

Originally worked in and near the outcrop as open cuts, the large mining operations are now chiefly underground. The present mines at Longdale, Alleghany County, Virginia, give information of much value, and serve as an illustration. Originally supplying a charcoal furnace requiring very limited supplies, open cuts were made at the outcrop, about 400 feet above the creek level, on the hillside. These ran as open cuts about 4000 feet in length, and about 100 feet in depth. At the outset these same workings supplied the coke furnaces, but at the depth of 100 feet it became impossible to keep up the walls, and underground mining was resorted to, and is now the only source of supply. In locating a tunnel, a shaft was started at the floor level of the open cut and sunk 200 feet, with a somewhat disappointing result, as the ore when struck was at that point only about 12 feet wide, and not of average quality. Notwithstanding, the tunnel was driven 1100 feet, and struck the ore at the depth of 200 feet, but about 150 feet north-east of the shaft. The ore at this point was 25 feet wide, and fully up to the average. From here adits were driven along the ore 1400 feet south-westerly and 1900 feet north-easterly. Still lower down the valley another tunnel was driven, striking the ore 120 feet below the bottom of the shaft, giving thorough drainage to the whole mine. From the surface to this lower level the ground is opened up by adits and winzes, making a splendid piece of mining property. The ore holds throughout, but turns and bends, and stands at every angle, conforming to the interstratified rocks from almost vertical to nearly flat. The mine is worked so that in coming back the pillars are drawn, the roof allowed to fall, and the hill completely robbed. No better opportunity for studying the peculiar characteristics of this ore, with its variations, both as to occurrence and quality, can anywhere be found. The changes in its approximate quantities of silica and manganese, frequently within a few feet, can be fairly detected by the eye. At the north-east end of the ore line, where a ravine occurs, the ore is entirely cut off, or, if continuous, it is at a very much greater depth.

These details have been gone into because the conditions found here are likely to be characteristic of this ore lead throughout the whole length of the State, and in localities now untouched, but before long to be brought on the market.

The total output of this property up to the first of this year has been about 750,000 gross tons, and at the present rate of consumption, say 250 tons a day, if dead work were to stop, there is enough ground opened to give four or five years' supply. The bottom of the lowest level is in solid ore everywhere, and the depth to which the ore may run is, of course, unknown.

At the Lowmoor Mine, a few miles away, a shaft has been sunk below water-level 200 feet, with the ore in first-class condition. Although all of the mining operations have to be conducted with explosives, four-fifths of the product must go through the washers to cleanse the ore of the accompanying clays. One double log washer will wash 100 tons a day, so that a plant of three washers keeps a furnace fully supplied with beautifully cleaned ore. Now as to the quality of the ore. The glowing accounts going the rounds of high-grade ores to be found in Virginia are misleading and inaccurate. As a rule, picked samples are taken for analysis, and the results given as indicative of usual conditions. The following is the average of a number of analyses of picked lump:—

	Per Cent.
Water	13·75
Silica	3·90
Alumina	2·50
Oxide iron	78·94
Oxide manganese	0·34
Lime	0·14
Magnesia	0·34
Phos. acid	0·35
Sulphur	Trace
Total	100·26
Iron	53·26
Phosphorus	0·064

These are visitors' and promoters' samples.

The result of analyses of a large number of furnace samples is:—

	Per Cent.
Metallic iron	48·09
Oxygen	20·48
Water	10·37
Silica	15·16
Alumina	2·81
Sulphur	None
Phosphorus	0·482
Manganese	0·83
Lime	0·28
Magnesia	0·24

The manganese and silica are the main sources of trouble; the manganese, according to most competent furnace authorities, frequently running up to 2 to 3 per cent. There is, however, an authority from which there can be no appeal, and which the writer personally and carefully obtained. The average yield of the ores, working by themselves, of one furnace in the district, is only 40 per cent. of iron, and the highest reached by any furnace does not exceed 43 per cent.

The massive lump ore is principally found near the surface, and steadily decreases in depth, over three-quarters of the ore as mined being wash; and it is the wash ore that carries the high silica. A safe business calculation requires that wherever the great Oriskany ore beds are found and worked, fancy percentages of iron must be discarded. As these ores are found in immediate proximity to high-grade limestones, and with splendid coke, at moderate cost, available, they form one section, at least, of a broad and stable foundation upon which a magnificent industry may be erected.

The brands of pig iron made by the furnaces working these ores exclusively are noted far and wide for their excellence, both for foundry and mill purposes.

Clinton, No. V.—The red hæmatites, or fossil ores No. V. of Professor Rogers, as far as Virginia is concerned at the present time, have simply a speculative interest, as they are nowhere mined or used in the State; but they are well known from Northern New York to Alabama. Used for many years at the Franklin and Onondaga Furnaces, Oneida and Onondaga Counties, New York—one of the principal sources of supply for seventy-five years for a score of charcoal furnaces, and later on for coke furnaces, chiefly in Bedford and Huntington Counties, Pennsylvania—they swing through Maryland, the entire length of Virginia from north-east to south-west; are being opened up at Middlesborough, Kentucky; are the principal ore for South Pittsburgh, Dayton, and Chattanooga furnaces in Tennessee and Rising Fawn, Georgia, and finally thicken up into the magnificent beds of the Red Mountain at Birmingham, Alabama. The maximum thickness of the bed is at or near Birmingham, and thins as it runs northward to 6, 5, and 3 feet, and down to 18 inches of good ore in Northern Virginia, Maryland, and Pennsylvania. Necessarily, there are local variations, some localities showing a greater thickness of bed than others. It is, therefore, not safe to predicate what one locality is going to do by what has been found at another. There is a very large amount of this ore to be had at a very reasonable cost, with proper mining. There is one point to which too little attention has been given, and which becomes a very serious factor in determining quantity. Of course, the promoter does not want to recognise the fact, but fact it is, beyond any peradventure, and by overwhelming evidence, that a marked change takes place in this ore below water-level, the iron in it running down, and being replaced by carbonate of lime or silica. Over very large areas now worked, a soft fossil ore above water-level, that shows from 52 per cent. to 55 per cent. of iron, and oftentimes not more than a trace of lime; below water-level, gives 28 per cent. to 34 per cent. iron, with carbonate of lime from 18 per cent. to 30 per cent.

At least one large furnace plant in the South, running principally on this lean, hard ore, uses no limestone whatever in its burden. One fact must be borne in mind, as far as Virginia is concerned—that it is only recently that railroads have opened up the country carrying this ore, and made a positive development possible. Notably this has been brought about by the building of the Clinch Valley extension of the Norfolk and Western Railroad to Wise County, Va.; the South Atlantic and Ohio Railroad from Bristol to Big Stone Gap, and the Charleston, Cincinnati, and Chicago Railroad, from North Carolina to Wise County, Va.

The published prospectus of the Big Stone Gap Company states that about two miles from that place, on the line of the South Atlantic and Ohio Railroad, this ore has been opened up at the base of Wallens Ridge, and shows a thickness of 39 inches of excellent soft ore. In the *Virginias* (May number, 1880, page 78), may be found an article by M. P. N. Moore, then connected with the Geological Survey of Kentucky, on the "Iron Ores Near Cumberland Gap, Va.," which is a succinct, clear, and forcible article on fossil ores. He found there two workable seams of ore—one soft, averaging 20 inches, and one hard, of 27 inches—about 75 to 100 feet apart. Careful sampling by him gave:

	Soft Ore.	Hard Ore.
	Per Cent.	Per Cent.
Ferric oxide	73·935	47·965
Alumina	5·776	2·130
Carbonate of lime	4·510	1·230
Magnesia	0·266	0·194
Phosphoric acid	0·319	0·575
Sulphuric acid	0·000	Trace
Silica and insoluble silicates	11·730	43·690
Combined water	3·850	4·000
Total	100·386	99·784
Metallic iron	51·754	33·575
Phosphorus	0·140	0·251

On the Massanuton Mountain, over 200 miles to the north-east, and fronting on the west the Shenandoah Valley Railroad, the same seams exist. Frederick Prime, Jr., is authority for the statement that on this mountain the ore is known as the "hard" and "soft" fossil ores, according as the predominant impurities are silica or lime. This differs from the conditions existing in Lower Tennessee and Alabama, but seems to verify what Mr. Moore found.

It is worse than folly to attempt to state with any precision what amount of workable ore can be found at any single locality, but we can safely sum up the general situation. This lead of ore is a stratified bed or seam; it extends, with variations as to quantity, but of a fairly positive quality, the length of the State. It is in reasonable proximity to railroads built and building, and with proper methods it can be profitably worked. Whether or not under water-level it loses its commercial value, there is, in the aggregate, a large amount to be had above water-level. The soft ore will be of great value for admixture with the silicious brown ores, especially in view of the fact that, as a rule, it carries low manganese and phosphorus; and it is likely to prove a factor of no mean importance in the future iron operations of the State.

Under No. V. comes the Medina sandstones, No. IV. of Rogers. In these measures are to be found large veins of what enthusiastic land-owners want to be iron ore; but it is simply a ferriferous sandstone, carrying from 18 per cent. to 30 per cent. of iron, and from 30 per cent. to 55 per cent. of silica, and, of course, worthless for furnace use.

No. III. of Rogers requires especial mention, as it carries valuable brown ores over considerable areas. These in former days served to supply a number of small charcoal furnaces scattered through the mountain valleys, but are not worked at present. They can be made readily available on Purgatory Mountain, near Buchanan, Botetourt County, Va., and the projected Western Virginia Railroad from Buchanan to the Kentucky line *viâ* Catawba Creek and Moccasin Gap will open up many miles of these ores. Recent investigations seem to point to large deposits lying in a fairly regular condition and susceptible of easy and cheap mining. A series of samples taken by E. D. Frazier, a careful and conservative prospector, and analysed by P. G Salom of Philadelphia, gave as follows:—

	Per Cent.
Metallic iron	43·61
Alumina	3·88
Silica	18·75
Sulphur	0·04
Phosphorus	0·48

The manganese, unfortunately, was not determined, but it is safe to assume that it will follow the usual run of mountain brown ores of from 0·6 to 1¼ per cent.

We are now brought to the consideration of what we may fairly assume to be the great ore-bearing measures of Virginia—I. and II. of Rogers.

No. I.—The Valley of Virginia is a part of the great valley extending from Canada to Alabama, and noted for its rich, fertile limestone lands, its great iron ore beds, its pure waters, its bracing health-giving climate, and its varied and picturesque scenery. It is called in New York the Walkill Valley, in Eastern Pennsylvania the Kitatinny, in Middle Pennsylvania the Lebanon or Cumberland, in Virginia the Shenandoah, James River, Roanoke, and New River, and farther South, the East Tennessee Valley. It extends throughout the whole of Virginia, about 330 miles in length, and from 12 to 30 miles in width. It is bounded on the south-east by the Blue Ridge Mountains and on the north-west by broken ridges, locally known as Walkers, North, and Little North Mountains. The Shenandoah Valley and the Norfolk and Western railroads run through its entire length, for many miles along the base of the Blue Ridge, which holds the Potsdam sandstones throughout, and on the top of which are the ferriferous shales, carrying the great brown ore deposits of the country. These ores widely vary in quantity, quality, and conditions, but in the aggregate seem to promise indefinite quantities. It is simply impossible, within the limits of this paper, to cover the innumerable matters of interest connected with this great field. Only a generalisation can be attempted. The occurrence of the ore is thus described by Prof. W. M. Fontaine of the University of Virginia: "We cannot in strictness call any of the deposits of the ferriferous shales veins or ledges, although ore may be, and usually is, found along certain definite bands. The deposits are lenticular masses or interrupted sheets of ore, that occur sometimes alone, or sometimes overlapping, in echelon, or more rarely radiating from a central point. Lines connecting the several masses in the direction of their greatest dimensions would fall within certain bands, and one mass may lie on the same line with another, so as to produce the appearance of one ledge or vein. The sheets and masses will, however, be found to be entirely enclosed in clay, and they are all formed by the concentrating action of concretionary forces that have collected this once diffused iron into masses that have more or less distinctly a concretionary structure, or that form beds of nodular ore, or crusts lying in an enclosing clay."

Beyond generalisation, any theorising on any special piece of ground is waste time. The only sure guide is good, hard, common sense, familiarity with existing workings, either by practice or close observation, combined with the pick and shovel. Of course it is assumed that there is a proper knowledge of the measures carrying the ore—their salient points, and what constitutes the walls of the deposit; but how the ore lies or how it is to be most advantageously worked must be decided as the work progresses. Horses of clay—sometimes of inches, at other times of many feet—are constantly encountered. The ore at any time may pinch to a trifling lead, and then open into lenticular masses, of varying and sometimes of enormous size.

While the general direction of the lead of ore is north-east and south-west, at places there are very great deflections, especially at the end of ridges and the foot of hills, where the ore will take a new direction, almost at right angles to the true lead.

Necessarily, under the old charcoal practice, the quantity of ore required was very small, and no mining, in the proper sense of the word, was done. When the ore outcropped and looked well, shallow pits would be opened on it, and as soon as one opening reached 10 or 20 feet in depth, it would be, as a rule, abandoned, and another surface point attacked. With the advent of the large coke furnaces, a different course was required. What may be reasonably looked for from these deposits can be best illustrated by an active mine some 12 miles from Roanoke, and owned and operated by the Crozer Iron Company. It lies well up on the mountain, some 400 feet above the water drainage of the locality. The ground was opened in 1882 and 1883, has been worked continuously ever since, and, until very recently, as an open cut over a large area. In some places the ore ground runs to the surface; in others there is a clay covering from 2 to 20 feet. This piece of ground, to the careful observer, becomes a complete and exhaustive object-lesson. There is to-day, ahead of a long and wide open cut, a face of at least 60 feet of wash ore ground, interspersed with boulders of solid ore of varying sizes, that will yield all through 1 ton of washed ore to 3 tons of dirt handled. On the floor of this cut a shaft was sunk for 60 feet through solid wash ground. A tunnel to strike this depth was driven for 1500 feet. The ore ground was struck at 400 feet, and the tunnel was driven for 1100 feet through, and leaving off in ore ground that gives 75 per cent. of ore in the dirt handled. On the floor a well was sunk for 30 feet through the same character of ground. The depth to which the ore may run is unknown, but over a large area the ore has been proved to be 150 feet deep, with no signs whatever of exhaustion.

Eminent geologists have for many years claimed great depth to the Blue Ridge ores, and these developments seem to warrant the correctness of their diagnosis. It must not be inferred that this condition of things exists everywhere along the lead; on the contrary, it is well known that there are many points where the ore is cut or squeezed out entirely, or is too limited in extent to be profitably worked, or the ore is too silicious and lean for any present attention, and some of these conditions may exist with very fair surface indications; but from what is actually known, and with the knowledge that the same deposits of ore, on their north-eastern continuation, sustained for many years the great iron industries of Lehigh and Berks Counties, Pennsylvania, and largely helped to make that wealthy, populous, and prosperous section, it is safe to infer that for many years to come Virginia possesses, from this source alone, excellent and ample supplies to build up and sustain an iron industry to which all she has done, and is now doing, will be as child's play. Many hundreds of analyses of these Potsdam ores have been made, covering every section of the ground between Maryland and Tennessee, but of which only a summary of the extremes can be given:—

Metallic iron, from 38 per cent. in wash to 57 per cent. in picked lump.
Silica, from 22 per cent. in wash to 3 per cent. in picked lump.
Manganese, from 0·10 per cent. to any per cent.
Phosphorus, from 0·10 per cent. to 3·5 per cent.
Alumina, from 0·5 per cent. to 3 per cent.
Lime, under 0·75 per cent.
Magnesia, under 0·50 per cent.
Sulphur, as an almost invariable rule, in the hundredths of 1 per cent., or inappreciable.

Two furnace owners in the district, largely using these ores, have kindly stated the results reached over a long time as to the average yield of these ores when prepared, showing from 44 to 46 per cent. of iron. In the main, lying in such close proximity to the railroads, the various deposits are readily reached by short branches of 1 to 6 miles in length.

No. II.—Along the Cripple Creek Extension of the Norfolk and Western Railroad, running through Pulaski and Wythe counties, and extending south-westerly well toward the North Carolina line, is another large ore field deserving particular notice. It is generally known as the Cripple Creek region, and contains a brown ore that has been famous in the past for its particular excellence in charcoal irons. It is unquestionably the highest grade of brown ore known in Virginia. It lies on the Lower Silurian limestones, No. II., in varying quantities, according to the folds of the limestone, but always of excellent quality. It is practically all worked in open cuts. The ore generally lies in a loamy, friable clay, but at times horses of a heavy, unctuous clay (locally called "buckfat") intrude. In some cases the deposits of ore ground are shallow, and at other times deep. The richness of the ground varies greatly—at times 4 yards of dirt yielding 1 yard of ore, at other times 12 to 1. The average of the district is stated as about 8 to 1. It is dug and handled with extraordinary ease and cheapness, where the ground is properly opened up, and good washing facilities afforded. It shows, by innumerable analyses and by continued furnace workings, a yield of over 48 per cent. of metallic iron, at times running up to 50 per cent. and 52 per cent., and, for a brown hæmatite, extraordinarily low phosphorus and manganese.

The following analyses by A. S. McCreath are fairly charactistic of the ore:—

	Per Cent.
Sesquioxide of iron	76·214
Sesquioxide of manganese	0·055
Oxides of nickel and cobalt	0·040
Alumina	2·360
Lime	0·820
Magnesia	0·480
Sulphuric acid	0·157
Phosphoric acid	0·171
Water	12·072
Silicious matter	7·480
Total	99·849
Metallic iron	53·350
Manganese	0·036
Sulphur	0·063
Phosphorus	0·075

It can readily be seen that this ore plays a very important part as an admixture with the Potsdam ores, with their higher phosphorus and manganese. How long these deposits can stand a persistent, heavy drain upon them it is impossible to definitely say, but that they are available for many years to come is unquestioned.

In leaving the brown ores of Nos. I. and II. it seems not amiss to call attention to the important part they may play in the near future in the manufacture of basic, and especially of open hearth basic, steel. Low silicon is the rule in all the irons produced in the district, and a great difficulty in the past has been to get high silicon in foundry irons. The writer has personally known of a lot of forge iron, taken at random out of stock in the furnace yards, and a score of analyses made by thoroughly competent chemists, showed that the silicon ran from a minimum of 0·30 per cent. to a maximum of 0·70 per cent., and an average of less than 0·50 per cent. By watching the ores as delivered, and properly charging the furnace, any desired percentage of phosphorus and manganese can be absolutely secured. Virginia may, indeed, be considered as one of the few natural homes of basic steel.

Incidentally, ore washing has been spoken of above. With the exception of the lump, which will not exceed one quarter, if that, of the output of the mines, the brown ores of the whole district, whether Nos. I., II., III., or VII. have to be washed to free them from the enclosing clays. One well-constructed double log washer will give an output of from 80 to 100 tons of ore per working day, according to the nature of the ground; and a picking belt attached thereto enables the washed ore to be freed from lump and pebbles of free silica. As a rule, jigs are not used, as generally they are not needed. Average ground requires the use of from 250 to 300 gallons of water a minute per washer. In many locations mountain streams and springs afford a supply, but there are many points where large mining operations can only be carried on by the establishment of pumping stations, and bringing the water a greater or lesser distance. There is one item of expense inseparably connected with every mining operation—viz., the connecting of mines with the main lines of railroad. In the portion of Virginia under consideration, the railroad officials have exhibited a broad, liberal policy in this respect that has largely lightened the labours of the producers, to the advantage of both.

Before considering the last and oldest of the ore-bearing rocks of Virginia (Archæn), a single word may be said in relation to a so-called "ore," lying to the eastward and under the Potsdam sandstones. It has been heralded far and wide as a Bessemer specular ore, in unlimited quantities, and of inestimable value. It is neither. It is simply a ferruginous sandstone, which can be traced along the Blue Ridge from one end of it to the other. It lies in stratified seams, of from two to six feet in width. Ordinarily, it carries under 30 per cent. of iron, and anywhere from 30 per cent. to 60 per cent. of silica. At one or two points there is a local improvement, which brings the iron up to 40 per cent. and the silica proportionately down. In such cases it is used in very small quantities to mix with the rank cold short brown ores to dilute the phosphorus and manganese, from which it is almost free.

In the older rocks are found two classes of ore—the magnetic and specular, and the gossan. While the quality of the former is high, it has never been worked on a large scale, owing to the fact that no large veins have as yet been developed. Major E. S. Hutter has been working some mines on the Franklin branch of the Virginia Midland Railway, in Pennsylvania County, for several years. He is authority for the statement that they can be traced for many miles, dip nearly vertically, and average from 2 to 5 feet in thickness. Carrying from 56 per cent. to 62 per cent. of iron, and oftentimes within Bessemer limits, these ores are valuable for admixture with the brown ores, and naturally improve the character of the iron.

In the same rocks, in Amherst County, below Lynchburg, Virginia, considerable money and labour were expended in developing the magnetics and speculars, but without any commercial results.

In another portion of the field, coming under the visitors' direct attention, a vein of fair magnetic ore, of about 50 per cent. iron, and 7 to 8 feet wide at the surface, at a depth of 75 feet, was entirely pinched out. In addition, the ore carried from 3 to 5.5 per cent. of sulphur. It is very possible that future research may show better conditions, but at the present time, with its very moderate development, it can scarcely be considered an important factor in Virginia iron-making.

There has been purposely left to the last a source of supply which is unique, and destined, in the writer's judgment, to have a widespread influence upon the iron business of South-Western Virginia—the gossan ore fields of Carroll County. For many years in the "long ago" this ore was worked in a small charcoal furnace in Floyd County, which adjoins Carroll, the iron requiring many miles of transportation over wretched country roads to reach a market. The output of the furnace was put mostly into castings for local use, and acquired wide notoriety by reason of the strength, toughness, and durability of the castings. Car wheels made from this iron proved of extraordinary lasting power and tenacity, the latter undoubtedly owing to the copper contained in the iron. Practically, however, the iron ore was of no value, the properties being worked for the copper underlying the gossan. In consequence, there is a splendid and unusual opening up of the ground by many hundred feet of tunnels and shafts, at different points. The lode dips at an angle varying from 40° to 70°, and also varies very greatly in width. There are at places surface widths of 300 to 500 feet. A conservative estimate would make an average width of say 50 feet throughout the whole lead, and an average depth of, say, 30 to 40 feet. In many places the ore comes directly to the surface, and generally has only from 2 to 5 feet of stripping. The lead is cut at frequent intervals by ravines, making the working of the ores almost child's play. There is no mining whatever. It will be an open cut or quarry, in which the ore is broken down and delivered to the cars. It is probable that a certain percentage of fine ores, lying near the surface and next to the walls, and somewhat mixed with the mica slates, may require washing, but the bulk of the ore quarried can be loaded directly into the cars. The following is the average of a large number of analyses, sampled by experienced furnacemen, and determined by competent chemists. It is proper to say that the samples were taken over a large area, from near the outcrop in the tunnels and shafts, and fairly represent the character of the ores:—

	Per Cent.
Metallic iron	50·275
Silica	8·335
Phosphorus	0·075
Alumina, from	2·5 to 4·00
Sulphur	0·486
Manganese	0·224
Lime, from	0·20 to 0·400
Magnesia	0·789
Copper	0·442
Lead	0·407

It is safe to assume that with proper care the ore can be had on a commercial scale to average 45 per cent. of iron.

One important statement remains to be made. It must be borne in mind that under the gossan occur the oxides of copper, red and black, with the carbonate in seams in the adjacent gossan. Below this follows the lode holding the grey and black sulphurets; beneath these the mundic rock to an unknown depth.

A diamond drill hole has, within the last few months, been drilled to the depth of 110 feet through, and leaving off in the mundic rock, which is a sulphuret of iron and copper. Two tests were made by roasting this mundic rock, simply for iron and sulphur. A pile of the mundic from near the surface was roasted with wood, and a piece of the drill core, at a depth of 110 feet, was heated in the laboratory, with the following results:—

	Surface Mundic before Roasting. Per Cent.	After Roasting. Per Cent.
Iron	54·26	63·96
Sulphur	33·97	0·623

	Drill Hole Mundic before Roasting Per Cent.	After Roasting Per Cent.
Iron	53·13	59·91
Sulphur	33·22	0·527

Assuming that modern experience and appliances can successfully handle this material on a commercial basis, so as to expel the sulphur, leaving the iron, the quantity to be obtained for this purpose is simply incalculable. Another "Blue Billy" factory can be started in this country. It is hard to conceive the effect upon the iron industries of Virginia, in consequence of the opening up of these ores. As the writer has had occasion to remark elsewhere, it is possible, by varying the mixtures in the furnaces, to produce every grade of iron. As far as is known, this is the first red-short ore that has to this date been made available in the South. It can be used by itself, or mixed with the brown ores of the district in close proximity, to produce a rank or mild red-short, neutral or slightly cold-short iron, while certain of the brown ores will give a rank cold-short iron. For castings, especially small ones for shelf hardware, &c., a low-priced iron can be made as fluid as water, and of very great strength. Its great point of value is that by admixture it will permit the use of hundreds of thousands of tons of the mountain brown ores capable of being cheaply mined and handled, that now, owing to their large percentages of phosphorus and manganese, are useless for present purposes. It is proper to state, in this connection, that very large deposits of this gossan are reported in Tennessee, on the south-western extension of the lode, but are at present unavailable by reason of their distance from any railroad. The gossans of Carroll are now reached by rail from the Norfolk and Western Railroad at two points—at the north-eastern end by a branch road, 13 miles long, from the Cripple Creek extension at Big Reed Island Creek, 25 miles from Pulaski, 37 miles from Max Meadows, 117 miles from Bristol, 52 miles from Radford, 89 miles from

Salem, 96 miles from Roanoke, and 149 miles from Lynchburg. The lower or south-western end of the lode is now reached by the Norfolk and western extension of the Cripple Creek Railroad, to meet the Cape Fear and Yadkin Valley Railroad, at the North Carolina line. This brings this part of the lead within 17 miles of Ivanhoe, 49 miles of Pulaski, 64 miles of Radford, 108 miles of Roanoke. It follows that this ore is commercially available at every furnace, either now blowing or building, or projected on the line of the Norfolk and Western and Shenandoah Valley railroads.

High grade limestones and dolomites are to be had everywhere throughout the great Valley of Virginia, and it is not necessary to encumber this paper with detailed descriptions or analyses.

In considering the possibilities of Virginia as an iron-producing district, it would be manifestly improper not to call attention to the fuels available, as, no matter how large the quantity, or how cheaply obtained the ores might be, they could not be utilised in the absence of a proper fuel.

The merits of the Flat Top coals and coke are now too widely known to warrant elaboration. The excellence of the coking coals of the New River district, on the Chesapeake and Ohio Railroad, has been too well tested in furnace practice for years past to admit of a doubt. The coking coals of the New River (Chesapeake and Ohio Railroad), upon which the furnaces at present working the Oriskany ores (No. VII., as above) depend, are elaborately treated by J. C. White, a recognised authority, in his report to the United States Geological Survey in 1884. He gives three seams of coal: the Nuttall, with its geological horizon on New River, about 400 feet below the top of XII.; and the Quinnimont and Fire Creek, from 300 to 400 feet below the Nuttall. These seams run from 3 feet to 4 feet in thickness. The coal literature of the country has been flooded for the last 10 to 15 years with analyses of all these coals and coke. Of course these vary according to the samples taken. It is believed that the following are fairly representative:—

Coals.

	Quinnimont.	Fire Creek.	Nuttall.
	Per Cent.	Per Cent.	Per Cent.
Fixed carbon	75·89	75·02	70·67
Volatile matter	18·19	22·34	25·35
Ash	4·68	1·47	2·10
Sulphur	0·30	0·56	0·57
Water	0·94	0·61	1·35

(*Transactions of the American Institute of Mining Engineers*, vol. viii. p. 261.)

Coke.

	Quinnimont. Per Cent.	Fire Creek. Per Cent.	Nuttall. Per Cent.
Carbon	93·11	92·18	92·22
Ash	5·94	6·68	7·53
Sulphur	0·82	0·61	0·92
	(T. Egleston.	Dr. Ricketts.	C. E. Dwight.)

The percentage of ash in the Fire Creek and Nuttall cokes is entirely too high for the ash shown in the coals, but the chances are that the coal samples were picked, while the coke shows the run of the mines.

The Flat Top seam, with its magnificent thickness of 6 to 11 feet, must necessarily be the source of supply to all of the furnaces located on or near the line of the Norfolk and Western Road, and it is in this section that the large present and near future development is taking and must take place.

A. S. McCreath, for many years connected with the Second Geological Survey of Pennsylvania, in an elaborate report on the New River and Cripple Creek mineral region, lately published, has a valuable addenda on the limestones and coals and coke, and from these the following are taken:—

Flat Top coals, averaging 15 samples:—	Per Cent.
Water	1·011
Volatile matter	18·812
Fixed carbon	74·256
Sulphur	0·730
Ash	5·191

From three large works at Pocahontas, in active operation, he selected samples of coke, which gave as follows:—

	No. 1.	No. 2.	No. 3.
	Per Cent.	Per Cent.	Per Cent.
Water	0·182	9·196	0·604
Volatile matter	0·719	0·494	1·059
Fixed carbon	92·248	92·585	92·516
Sulphur	0·565	0·677	0·911
Ash	6·286	6·048	4·910
Totals	100·000	100·000	100·000

As one of the possibilities of successfully making iron in Virginia, it does not seem unfair to make the following comparison, as quoted by Mr. McCreath, especially as the analyses of the cokes of other districts have been for a long time public property:—

	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent
1. Pocahontas coke, average of three samples	0·347	0·757	92·550	0.597	5·749
2. Birmingham, Alabama, average of four samples	0·157	0·803	87·299	1·195	10·545
3. Chattanooga, Tennessee, average of four samples	0·447	1·101	80·513	1·595	16·344
4. Connellsville, Pennsylvania, average of three samples	0·060	0·427	88·962	0·810	9·741

The growth of the Flat Top coals from nothing in the census year of 1880 to nearly 2,000,000 tons in 1890, and of coke from nothing to many hundreds of thousands of tons, with an increasing demand which present facilities cannot possibly meet, tells the story of what it is.

The following table of distances to furnaces now in operation, building, or projected, may prove not uninteresting:—

From Pocahontas to Graham, 10 miles; to Radford, 75 miles; to Pulaski, 90 miles; to Max Meadows, 103 miles; to Bristol, 182 miles; to Ivanhoe, 122 miles; to Salem, 112 miles; to Roanoke, 119 miles; to Lynchburg, 172 miles; to Glasgow, 163 miles; to Buena Vista, 173 miles; to Basic City, 215 miles, and to Shenandoah, 251 miles.

The cokes from the New River district, on the Chesapeake and Ohio Railway, 112 miles to Lowmoor, 118 miles to Longdale, 121 miles to Wilton, 133 miles to Goshen, 160 miles to Glasgow, 175 miles to Buena Vista, 198 miles to Lynchburg, 178 miles to Basic City and 214 miles to Shenandoah.

It is not within the province of this paper to give any figures of cost. The reader must form his own conclusions, based upon his own experience, as to the prices at which materials of the quality as given, and lying in proximity as described, can be handled by prudent and practised business men. The visitor interested in obtaining information on this point will find abundant sources to gather what he desires.

The writer claims the right to say, with a large personal knowledge of different mineral sections of the country, and with no desire to detract in any way from the merits of many other districts in this favoured land, lavishly blessed by nature, that taking into consideration the variety and position of the various mineral resources of Virginia, it is the most remarkable and interesting mineral field that has ever come under his examination.

In closing this unreasonably, but unavoidably, lengthy paper, he desires to express his acknowledgments for the information obtained from the valuable papers and reports of Drs. W. H. Ruffner and Egleston; Professors Campbell and Fontaine; Messrs. Prime, Moore and McCreath, and especially to the invaluable publication by Major Jed Hotchkiss, of Staunton, Virginia, of *The Virginias* from 1880 to 1885.

MASSICKS & CROOKE'S AMERICAN PATENT FIRE-BRICK HOT-BLAST STOVES.

BY WALTER CROOKE, MILLOM, CUMBERLAND.

REGENERATIVE hot-blast stoves are now in general use in all parts of the world, and are so well understood and appreciated that I need not take up your time with an account of their history and introduction into the United States. My object in writing this paper is to give you a short description of a stove that is now being very favourably received and adopted here (see drawing). The stove was first introduced into this country in 1887 by M'Clure & Shuler (now M'Clure & Amsler), who have the management of the patent right in the United States.

The English design had to be modified to suit the exigencies of American blast furnace practice, which, in many respects, widely differs from our English experience.

In the first place, the fire-bricks used in America expand to an extent unknown in England, and it became necessary to make special provision for this by increasing the number of cross walls, and by leaving a space at the top of the stove through which the lining could expand. The expansion latterly was, however, more difficult to provide for, as the combustion chamber in the centre, being the hottest part of the stove, must necessarily expand more than the outer walls, and therefore tend to squeeze up the flue openings.

On first introducing these stoves to American ironmasters, a feeling seemed to prevail that a "four pass" stove did not utilise the whole of its surface. They also had an idea that the "two pass" stove let the burning gas go before all the duty had been extracted from it, so that it was found necessary to design a stove of a special character to suit their wishes. Hence the "three pass" chimney-top stove now before your notice, the advantage claimed for which is that each stove is independent, requiring no underground chimney-flue or stack, and can be erected at a very light cost. The working of these stoves has proved to be very successful wherever they have been introduced.

The first stoves built in this country (U.S.A.) were put up for Messrs. Shoenberger, Speer, & Co., Pittsburgh, Pa. They were three in number, 16 feet 6 inches in diameter, and 57 feet high to the eaves; the furnace was 14 feet bosh and 62 feet high, and at that time made 450 to 500 tons per week with pipe stoves. The difference found on blowing-in the improved plant was at once apparent; the output rose to 800 tons per week, and the fuel consumption diminished to 1900 and 2000 lbs. per ton of iron, instead of from 2700 to 3000 lbs. These stoves have been continuously in blast for a period of nearly three years, and beyond a few hours' stoppage for cleaning, have not cost a cent for repairs.

Since that time the Massicks & Crooke's stoves, with three passes, have been used in every iron-making section of the country, and have well proved their efficiency.

The method of cleaning employed in the English stove has substantially been retained, but various improvements have been introduced which add greatly to effectiveness and speed of cleaning. The second pass (that nearest the combustion chamber) is cleaned with a scraper which has been specially designed to accommodate itself to any little irregularities in the flue walls. For the third or outside pass an automatic cleaning door was devised, which is fitted on to each bottom cleaning door in turn. The stove is then filled with air at blast pressure, and the catch on the door is knocked off, when the imprisoned air rushes through the flues towards the door, carrying with it any loose dust that there may be in them. For dislodging such dust as may adhere to the walls, a wire brush is used, operating in the same manner as the scraper in the second pass.

Among minor details, the slide gas valve has been abandoned, and a positive cut-off valve, universally used in this country, has been substituted. The Massicks & Crooke's hot-blast valve has been retained, and has given great satisfaction in respect of its simplicity and durability.

The duty required of hot-blast stoves in America is much heavier than in England, an ordinary-sized furnace, say 18 feet bosh and 75 feet high, being blown at a rate of 20,000 cubic feet of air per minute at a temperature of 1500° Fahr. This of course makes it necessary to heat the stove up to a very high temperature, and so much greater is the duty required than formerly that devices which have previously given the greatest satisfaction fail to meet the present requirements.

The stoves at the Tod Furnace, owned by the Brier Hill Iron and Coal Company, Youngstown, Ohio, 16 feet 6 inches diameter, and 57 feet to the eaves, have been doing excellent work. The furnace is 15 feet 6 inches bosh, by 70 feet high, and has been making 185 gross tons* per day on a very low consumption of coke, viz., 1700 to 1800 lbs. per gross ton of iron; the amount of air passing through the stoves being 17,000 cubic feet per minute, at a temperature of 1300 to 1500° Fahr., with a loss of from 100 to 120 degrees in one hour's blow.

You can very readily see from the above that it was necessary to increase the volume of brickwork, and also to adopt a more thorough system of binding and bracing the circular walls than hitherto, so as to avoid all possibility of the walls moving out of their position, and in order to allow them to expand and contract at will without shearing off the bricks.

In order to give you an idea of the approximate cost of a set of three stoves of various sizes that M'Clure & Amsler have been building, it may be interesting here to notice the quantity of material required and the average cost of the same, viz.:—

Three Stoves, 16 feet 6 inches by 60 feet.

Wrought iron	175,000 lbs.	Average cost, 17,521 dols., or £3650, 4s. 2d.
Castings	41,000 „	
Bricks, 1st Quality	180,000	
„ 3rd „	203,000	

Three Stoves, 18 feet by 60 feet.

Wrought iron	188,500 lbs.	Average cost, 19,934 dols., or £4152, 18s. 4d.
Castings	42,000 „	
Bricks, 1st Quality	235,000	
„ 3rd „	224,000	

Three Stoves, 19 feet 6 inches by 65 feet.

Wrought iron	220,000 lbs.	Average cost, 23,839 dols., or £4966, 9s. 2d.
Castings	46,000 „	
Bricks, 1st Quality	256,000	
„ 3rd „	342,000	

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* United States net ton=2000 lbs.; gross ton=2240 lbs.

Three Stoves, 21 feet by 70 feet.

Wrought iron	282,000 lbs.	Average cost, 30,872 dols., or £6431, 13s. 4d.
Castings	53,000 „	
Bricks, 1st Quality	373,000	
„ 3rd „	400,000	

The following is a list of the stoves now in operation and in course of construction:—

Stoves in Operation.

	Stoves.	Ft.	In.		Ft.
Shoenberger, Speer, & Co., Pittsburgh, Pa.	6	16	6	by	57
Williamson Iron Co., Birmingham, Ala.	3	16	6	„	57
Illinois Steel Co., Chicago, Ill. (Bayview)	6	18	0	„	60
„ „ „ (N. Chicago)	3	18	0	„	60
„ „ „ (Joliet)	4	19	6	„	70
Thomas Furnace Co., Niles, Ohio	3	16	6	„	57
Brier Hill Iron & Coal Co., Youngstown, Ohio (Tod Furnace)	3	16	6	„	57
„ „ „ „ (Grace Furnace)	3	19	6	„	65
Carrie Furnace Co., Pittsburgh, Pa.	4	19	6	„	65
Chicago Furnace Co., Chicago, Ill.	1	16	6	„	57
Bellaire Nail Works, Bellaire, Ohio	3	18	0	„	65
Riverside Iron Works, Wheeling, W.Va.	3	19	6	„	60
Missouri Furnace Co., St. Louis, Mo.	1	18	0	„	60
Total	43				

Stoves in Course of Construction.

	Stoves.	Ft.	In.		Ft.
Illinois Steel Co., Chicago, Ill. (S. Chicago)	16	22	0	by	70
Paducah Iron Co., Paducah, Ky.	2	16	6	„	57
Roanoke Iron Co., Roanoke, Va.	4	18	0	„	60
Vanderbilt Iron & Steel Co., Birmingham, Al.	3	16	6	„	60
Bellaire Nail Works, Bellaire, Ohio	1	18	0	„	65
Riverside Iron Works, Wheeling, W.Va.	3	18	0	„	65
Total	29				

As no doubt many of the members of the Institute will see these stoves in the course of their visit to the United States, I trust that this short paper will not be uninteresting.

APPENDIX.

PRESIDENTIAL ADDRESS OF THE HON. A. S. HEWITT.*

After an interval of fourteen years, saddened for all of us by the death of David Thomas, the father of the anthracite iron trade, first President of the Institute, and by the untimely loss of his successor, Alexander L. Holley, whose memory we are about to honour by loving services, the members of the American Institute of Mining Engineers have conferred upon me for the second time the office of President, under circumstances similar to those which led to the choice in 1876. Then the whole world was represented at the great exposition of industry which was held in Philadelphia to celebrate the one-hundreth anniversary of our declaration of political independence. In 1890 it is our privilege to receive as guests the members of the Iron and Steel Institute, who, with singular and graceful felicity, have appointed a meeting in the United States in the year when we pass from the second to the first place in the international column of the production of iron, and thus celebrate our industrial independence. For the honour of being chosen to extend to our distinguished guests the right hand of fellowship and a hearty welcome, I return to my associates the grateful acknowledgment of one whose chief claim to your favour is to be found in his love for the professional occupation in which we are all engaged, and in his efforts, public and private, to promote its advancement into new fields of usefulness.

In order to indicate the full significance of the visit of our foreign guests at this time, it will be proper to explain briefly the origin, aims, and work of the Iron and Steel Institute. It unquestionably owes its birth to the International Expositions held in London in 1851 and 1862, and in Paris in 1867. These expositions served to break down the jealousies of nationality and to diffuse a better knowledge of industrial processes. Trade secrets, which had been carefully guarded, became common property; manufacturers who had previously regarded themselves as rivals formed bonds of union and ties of friendship, as the results of an intercourse which broke down all prejudices and led them to see that their highest interests would be promoted by the free interchange of experience and ideas. The progress of the world in the arts of civilisation since 1851 has been phenomenal. In fact, the face of the industrial world may be said to have been entirely reconstructed since the time when the first International Exposition was held. The figures which I shall adduce in regard to the development of the iron and steel industries during the last decade will make it clear that new agencies have been at work for the amelioration of humanity and the progress of civilisation. Among these agencies I can think of none more powerful than the influence exerted by the Iron and Steel Institute through its meetings, its discussions, and the publication of its Transactions. The comprehensive nature of its work, and the absolute honesty and frankness with which it has been carried on, afford the best illustration of the catholicity of the age in which we are so fortunate as to live, and give promise of the good time when all barriers to the intercourse of men shall be broken down, and it shall be demonstrated that the true interests of mankind are best promoted by the free play of the laws of nature.

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* **This address of Mr. Hewitt, as President of the American Institute of Mining Engineers, was circulated during the meetings of the Iron and Steel Institute.**

So far as I know, this was the first considerable organisation of a special industrial interest, deliberately formed for the acquisition and diffusion of scientific and practical knowledge, independently of the question of profit and commercial results. I venture to say that in the history of the human race there is nothing approaching the records of the Institute in the disclosure to the whole world of the most valuable and intricate processes, in previous times regarded as special secrets and carefully concealed as the property of private establishments. Although British in name, the Institute has invited and secured the co-operation of the ablest men, both practical and scientific, in all countries; and its membership is as widely diffused as are the materials of the great industry to which it is devoted.

Its organisation dates from 1869, when it was formed with 292 members; to-day it numbers over 1600. In 1870 the world's product of pig iron was 11,900,000 tons; in 1889 it amounted to 24,869,534 tons. Meanwhile the processes of manufacture have been revolutionised, and a large portion of the world's consumption has been changed from iron to steel in consequence of the improvements which have been either originated by members of the Institute, or made the common property of mankind by the complete disclosures of new discoveries and processes made in its Transactions. It is not too much to say that the tone of the trade has been raised to a plane of intelligence and liberality which would have been absolutely incomprehensible to the past generation, and which opens for those who are to come after us a new world of generous competition in promoting the welfare of the race. The history of the achievements of the Iron and Steel Institute thus forms a complete answer to those who are inclined to take a pessimistic view of humanity; for it has shown how all the members of the largest branch of industry, lying at the very foundation of civilisation, can be brought to work together for the common good and for the more equitable distribution of the products of human effort.

It has been from time to time the wise practice of the Institute to hold meetings outside of Great Britain, in countries where there is a considerable development of the iron and steel business. It has reserved, however, its meeting in this country until, by the inevitable growth of population and the consequent development of our resources, we have become the largest producers of pig iron and of steel among the nations of the world.

In recognition of this felicitous compliment, we can assure our guests that the time has been accelerated by many years in consequence of the inventions of members of the Iron and Steel Institute, chief among whom, we are glad to say, still survives the conspicuous personality of Sir Henry Bessemer, *clarum et venerabile nomen*, whose absence on this occasion, in consequence of his advanced years, causes a feeling of profound regret throughout the length and breadth of the land. They have come largely to see the fruits of their own good work, and it will be our fault if they do not receive a hospitality which will remove from their hearts anything of regret that the primacy in the production of iron and steel is passing from the parent to the child. If they have divided their inheritance with us, we at least are ready to acknowledge the obligation, and as hosts to tender them the first fruits of the magnificent resources with which we have been endowed, and which we have been enabled to develop with the co-operation, counsel, and large experience of the mother-country.

Our own Institute, now consisting of over 2000 members, and the Verein Deutscher Eisenhüttenleute of over 1000 members, and represented here by a numerous delegation, both owe their existence to the example of the parent society, whose record they have striven to emulate, and whose pre-eminence is acknowledged with admiration and gratitude.

Having thus endeavoured to express our profound appreciation of the honour of their visit to this country, I proceed now, in a general way, to indicate the subjects to which their attention will necessarily be directed in order to understand the condition of the iron and steel business in this country, and its further prospects. I shall carefully abstain, however, from all description of the great establishments which have grown up in the last ten years, of the improved processes which they employ, and of the technical details which will be presented at the international meetings by representatives of both continents, fully qualified to deal with the scientific and practical phases of the business. I shall devote what I have to say to a consideration rather of the conditions under which the iron and steel business has grown to its present proportions, and to the difficulties in the way of its development on the scale demanded by the growth of the world and the progress of civilisation.'

The possession of fuel determines the direction, growth, and remuneration of modern industry. The mineral fuel of the world is largely under the control of the Teutonic races, and hence the iron and steel business has been most extensively developed in Great Britain, Germany, and the United States. Of these three countries, the last-named has the largest and most cheaply worked deposits of fuel. Of the country lying east of the Mississippi River, the coal-field occupies about 135,000 square miles, generally covered by a fertile soil, traversed by natural water-ways, and tapped by railways aggregating over 100,000 miles in length. Around the edges of this vast coal-field the older geological formations bring to the surface the deposits of iron ore belonging to the successive strata from the crystalline rocks to the recent tertiary deposits. The accumulation of ore is, in some portions of the country, upon a scale of grandeur which may well excite the wonder of the beholder. The connection between these vast deposits of ore, and the fuel required for smelting them is, as a rule, remarkably convenient and easy. The magnetites of New York and New Jersey have been connected by rail with the anthracites of Pennsylvania, so that they may be brought together upon favourable conditions. The hematites and specular ores of Lake Superior reach the coals of Illinois and Ohio by a water-communication which has been so perfected as to reduce the cost of transport below one dollar per ton. The magnificent deposit at Cornwall, in Pennsylvania, which our guests will visit, is within forty miles of anthracite coal, and accessible to coke at rates which leave nothing to be desired. When we pass to the south, we find in Alabama that the coal and ore are usually within twenty-five miles of each other, and sometimes to be found lying one over the other upon the same property. Between Pennsylvania and Alabama the ranges of ore extend in and along the Appalachian chain, in close proximity to admirable fuel, which, during the last few years, has been made accessible by railways and canals.

When the Government of the United States was organised under the

Constitution of 1789, the existence of these coal-fields was unknown, and only a few deposits of iron ore skirting the coast had been opened for the use of charcoal as a fuel. The first census of the United States, made just a hundred years ago, disclosed a population of not quite 4,000,000 of inhabitants, residing near the coast, without capital, and with no industries developed, except those of a domestic nature, carried on according to the rude methods of a primitive civilisation. No steam-engine had as yet been erected within our borders, and no other means of transportation existed except the water-ways which had been provided by Nature, or the rough roads over which communication was kept up with difficulty between sparse and distant settlements. Except in natural resources, no civilised people was ever poorer than was this nation at the close of the revolutionary war, but none was ever endowed with so much hope, courage, and intellectual activity, or with so grand a field for the exercise of these good qualities. Moreover, our fathers were God-fearing men, who thoroughly believed that "the earth was the Lord's, and that they were His people." In 1776 they had proclaimed political independence, but it was not until 1789 that they became a nation. The same instrument which decreed the fusion of the States into one Union as the fundamental condition of nationality, to be subsequently maintained by a war which cost eight thousand millions of dollars and the sacrifice of more than a million of lives, and is attested to-day by a pension roll of over one hundred millions of dollars per annum, laid the foundation of industrial progress and independence by declaring that "no State shall pass any law impairing the obligation of contracts," and that "no man shall be deprived of life, liberty, or property without due process of law." With the assurance of protection thus afforded, the young nation started boldly out to conquer sea and land. The genius of Alexander Hamilton set in motion the wheels of progress by the honest funding of the public debt, and by encouraging the movements of a race of men ready alike to vex the ocean with their sails and to drive back the Indian by their steady march beyond the Alleghenies, disclosing the mineral wealth that was stored within the mountain fastnesses. Roads were built, over which toiled the cumbrous Pennsylvania wagons; and the men who had marched with bleeding feet from New Jersey to Yorktown, crossed the Allegheny mountains, and occupied the rich regions of Ohio, Tennessee, and Kentucky. Their toilsome paths were over the coal-beds, and in their wake followed the canals and railroads which have enabled us so to assemble the raw materials as to place ourselves, within a century, at the head of the nations in the production of iron and steel. In these early days there was no time for strikes and no provocation for boycotts. There were no capitalists; and the only walking-delegates to be found were those who travelled on foot to represent their communities either in the Legislature or in Congress. They were all Americans, made brothers by mutual trials and struggles; not a mongrel mass of foreign races, ignorant of the true basis of personal liberty which our fathers had incorporated into the constitution as the perpetual guarantee of freedom and progress. In vindication of these fundamental principles of our national existence, we may yet have to make greater sacrifices of men and money than were required for the maintenance of the Union. For, let our visitors from abroad be assured, the people who have been able to conquer a continent in a hundred years will not allow themselves to be deprived of the right to life, liberty, and the pursuit of happiness at the dictation of any organisation, either of capital or of labour, however powerful.

Until communications by canal or rail had been established between the coal-fields and the ore beds, the progress of the iron business was necessarily slow. Its subsequent story is told in the following table, showing the comparative rate of increase in population and in the production of iron :—

Year.	Production of Pig Iron.	Rate of Increase.	Population.	Rate of Increase.
	Tons.	Per Cent.		Per Cent.
1830	165,000	...	12,866,020	32·51
1840	315,000	99	17,069,453	33·52
1850	564,000	80	23,191,876	35·83
1860	919,770 of 2000 lbs.	65	31,443,321	35·11
1870	1,865,000 ,,	105	38,558,371	22·65
1880	4,295,414 ,,	133	50,155,783	30·08
1890	9,579,077 ,,	130	64,000,000	28·00

This table brings out the striking conclusion that the production of pig iron has always increased more rapidly than the population, and that the ratio is an increasing one. Between 1830 and 1860 the production of iron increased twice as fast as the population. Between 1860 and 1890 it increased four times as rapidly, thus proving that the national wealth continues to grow from decade to decade at a rate of acceleration of which the world affords no previous example. Inasmuch as during all this time we have imported iron in addition to our production, it follows that the consumption per capita has also increased more rapidly than population. In 1855, according to careful calculations which I made at that time, we were consuming iron at the rate of 117 pounds per head; whereas in 1890 the consumption has increased to rather more than 300 pounds per head, the whole of which, for the first time in our history, we are producing within our own borders.

Great Britain, on the other hand, produces more iron than it consumes, and is still the largest per capita producer in the world. In 1889, with a production of 9,321,563 tons of 2000 pounds, and with a population estimated at 38,000,000, the production reached the large figure of 495 pounds per head. Deducting the exports, Great Britain is now consuming 250 pounds per head * against a consumption of 144 pounds in 1855. But the production of iron in Great Britain appears to be now very nearly stationary, as will appear from the following table, giving the tonnage produced since 1880:—

1880	7,749,233
1881	8,144,449
1882	8,586,680
1883	8,529,300
1884	7,811,727
1885	7,415,469
1886	7,009,754
1887	7,559,518
1888	7,998,969
1889	8,245,336

This table discloses the fact that in 1889 Great Britain, while making an increase over 1888, was not able to reach the product of the years 1882 or 1883. It may, therefore, be concluded that no considerable increase of production is to be expected, especially in view of the facts that the present production is only maintained by the importation of foreign iron ores to the extent of 20·4 per cent. of the total ore consumption, and that the ratio of foreign ore consumed is increasing.

In the United States the case is otherwise. We have been able to increase our total product year by year, without increasing the importation of foreign ores, none of which are in fact necessary to the existence and growth of the business, although in some localities near the coast foreign ores are desirable for the production of Bessemer pig. Assuming, then, that the production of Great Britain is not likely to be increased, and that the growth in the consumption of iron is to go on with the increase of population and the progress of industry in the future as in the past, we are in a position to estimate the demands which will be made upon the resources of the United States for the next ten years. The population in 1900, allowing the same rate of increase of 28 per cent. as in the last decade, will be 82,000,000. A consumption of 300 pounds per head will require 24,600,000,000 pounds of iron, equal to 14,300,000 tons of 2000 pounds. If, in accordance with the accelerated ratio of consumption, which has trebled since 1855,

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* In 1890, as shown in Sir James Kitson's address (p. 10), the average per capita consumption was 303 lbs.—Ed.

the per capita demands shall rise to 400 pounds, the total tonnage required will be 16,400,000 tons of 2000 pounds, equivalent to 14,800,000 gross tons. The consumption of the world in 1889 is estimated at 24,867,534 gross tons, of which we produced 30 per. cent., and Great Britain 33 per cent. The consumption of the world has increased in eleven years from 14,117,902 tons to 24,869,534 tons, or nearly 11,000,000 tons. Assuming that the coming ten years will require an equal increase (and it is likely to require more), the United States must supply 7,000,000 tons, and the rest of the world 3,000,000, in order that the two continents may not be forced to draw supplies from each other. I think it is safe to estimate, therefore, that in 1900 the world will require 35,000,000 gross tons of iron, of which the United States must supply 45 per cent., and the other iron-producing countries the remainder, in the proportion of half to Great Britain and half to Germany, France, Belgium, and the other smaller producers.

The question presents itself, whether this vast demand can be met without such an increase in price as will tend to restrict the use of iron within narrower limits. The increased call upon the European countries is too small to make any embarrassment, except such as may arise from the fuel and food questions, both of which are serious problems in the European industrial world. The answer to the question must, therefore, come from the United States; and in view of the changed relations of the two continents in regard to the supply of iron, it will be seen that tariff legislation will henceforth play no part in the solution of the problem. According to the traditions of the Institute of Mining Engineers, it is not permissible to discuss commercial questions; but there is no impropriety in calling attention to the fact that one of the perplexing elements in the consideration of the future of the iron business is removed from the problem when the conclusion is reached that henceforth it will task the ability of Europe to supply its own demand for crude iron, and that the United States must look to its own resources for the supply of the great demands of the coming century. It is quite evident that the only effect of transferring any considerable portion of this demand from the United States to Europe will be to raise the price of iron, so that thenceforth the competition in the open markets of the world will be more favourable to our manufacturers than it has been in the past.

So far as we are concerned, then, the question is substantially whether this country can nearly double its production in the next ten years without so seriously increasing the present cost of iron as to restrict the consumption, and arrest the rate of progress at which the world is now moving forward.

The production of iron involves the five elements of fuel, ores, capital, labour, and skill.

Fuel.—Upon reference to the map of the United States on which Mr. Kunhardt has outlined the coalfields, showing their relations to the deposits of iron ore, it becomes evident that there is practically no limit to the quantity of coal which can be supplied on demand. The growth of this product corresponds very closely with that of the production of pig iron:—

	Tons Mined.
1870	28,312,581
1880	63,773,603
1889	132,419,342

More than doubling itself in each decade. The capacity for production is always so far in excess of demand, that it is often necessary to limit the amount forwarded to market, by the action of the great corporations engaged in the mining and transportation of coal. Doubtless there will be required to meet the demand in A.D. 1900 nearly or quite 300,000,000 tons of coal. This can readily be had from the fields which are now open and have direct communication with the deposits of iron ores.

Iron Ores.—The map shows also the regions from which we now derive our present supplies. That these can be doubled in ten years does not admit of a doubt. Probably the most remarkable points of interest to our guests will be the great deposits of Cornwall, in Pennsylvania, of the Marquette, Menominee, Gogebic, and Vermilion ranges in the Lake Superior region, and the ores of Tennessee and Alabama, extending in an unbroken vein for hundreds of miles along the flanks of the great Appalachian coalfield. The following statement of the growth of the business in the Lake Superior region will serve to show the facility with which the supply can be increased:—

	Tons Mined.
1885	2,466,372
1886	3,568,022
1887	4,730,577
1888	5,063,693
1889	7,292,754

Showing that in five years the quantity has increased threefold.

The South is practically a virgin country, in which the production of ore is in its infancy; but the development is already phenomenal, and even if the other regions ceased producing ore, the Southern States could readily supply the deficiency. It is remarkable also that the vast deposits of hematites and red fossiliferous ores with which the South is endowed are adapted to the "basic" process, while the ores of Lake Superior are suited to the "acid" process. Thus the two sections are practically the complements of each other in the work of supplying the needs of the country for steel. It will doubtless excite surprise in the minds of our visitors to find that the basic process has made no progress in this country. The delay has been due partly to the recent development of the Southern ores, and partly to the illiberal spirit in which the basic patents have been managed. But it will not longer be possible to arrest the manifold destiny of the South, which is now erecting a large number of furnaces, the product of which must find a market through the basic process.

Capital.—The total wealth of the United States will be reported in the census just completed, but the figures are not yet available. In 1880 the amount was 43,642,000,000 dollars, which is equal to 870 dollars per head of population. The rate of increase of population for the previous decade was 30·13 per cent., and of the per capita wealth 45·47 per cent. During the decade ending in 1890, the rate of increase of population is 28 per cent., and if the ratio of increase in wealth is only the same as in the previous decade, it will amount to 42 per cent., making the per capita wealth 1235 dollars. The actual figures will undoubtedly show a larger amount for each inhabitant.

In Great Britain, according to Robert Giffen, the wealth per capita at present is £270, equal to 1300 dollars, so that the two countries are probably on an equality of wealth as to each inhabitant; but the aggregate wealth of this country now, and for the first time, exceeds that of Great Britain, although the amount of floating capital is larger there than here. But it must be remembered that the floating capital of the world is now practically mobilised, so that, if a deficiency exists in the United States, it is promptly supplied from abroad.

Now, the wealth of Great Britain has been adequate for the annual production of 495 lbs. of pig-iron per head. It cannot, therefore, be doubted that, with equivalent wealth, we could meet a demand of the same extent. If such a result should be reached in 1900, we should produce 19,000,000 of gross tons of iron, which exceeds the estimate already made as to the probable requirements by more than 1,000,000 tons. The very large absorption of capital in the erection of new furnaces in the Southern States during the last two years, supplying a capacity of at least 1,000,000 tons per annum, when the furnaces now under construction shall have been completed, has been readily met; and this goes to show that there is no practical difficulty in getting the means to supply any quantity of iron which the market will take.

Labour.—For the supply of the raw materials and the smelting of our present product of pig iron, about 200,000 men are required. The labour of one man, therefore, now suffices to produce rather more than 40 tons of pig iron per annum. To produce, in 1900, double the quantity now produced, will require the labour of 200,000 additional men. This is not more than the number of male emigrants who come annually to our shores, and it is but a small percentage of the normal increase of our population, which, between now and 1900, will reach at least 16,000,000 persons. So far, therefore, as the supply of labour for the increased production is concerned, we need be under no apprehension.

Skill.—Our foreign visitors are about to make a critical survey of the iron and steel works of the country, and their judgment as to efficiency and management will be accepted as final. In 1876, when this country had not fully entered upon the manufacture of steel, in which it now leads the world, producing one-third of the whole supply, the foreign engineers bore testimony to the superiority of our appliances, and to the greater yield per man. Our methods and labour-saving machines were at once copied by the best European establishments. I think I am safe in saying that we have not gone backwards in the interval, and that our guests will still find something of value to be given in exchange for the priceless contributions which, since 1876, they have so generously made to the progress of metallurgy in this and other countries. At any rate, I think we have been quite ready to learn, and to take advantage of every advance, at home and abroad, so that our technique will be found to be fully up to the highest known standard of excellence.

It seems to be clear, then, that in all the elements required to meet the increased demands of the world for iron and steel, the United States are abundantly equipped. But it is not enough to have adequate supplies of ore and fuel. They must be so situated as to be brought cheaply together at the place of production. This condition has recently formed the subject of an investigation by the Commissioner of Labour, the Hon. Carroll D. Wright, and his results, so far as published, serve to show that the assemblage of material required per ton of pig iron can be made with as little labour and expense, on the average, in this country as in any country of the world. Indeed, it may be asserted that in no other country can the quantity required for the production of 20,000,000 tons per annum be brought together so cheaply, if at all.

The most remarkable fact in this connection is the constant reduction in the cost of transportation, which has been mainly accomplished by the extension and improvement of the railroad system of the country. It appears by the table herewith appended, that the average rate of freights on all classes of goods since 1882 has been reduced from 1·236 cents per ton per mile to 0·976 in 1889.

The following statement, from *Poor's Manual*, shows the volume of freight traffic on all the railroads of the United States during the eight years 1882–89 :—

Years.	Tons Freight Moved.	Tons Freight Moved One Mile.	Average Rate per Ton per Mile.	Average Haul per Ton.
	Tons.	Miles.	Cents.	Miles.
1822	360,490,375	39,302,209,249	1·236	109·02
1883	400,453,439	44,064,923,445	1·236	110·04
1884	399,074,749	44,725,207,677	1·124	112·07
1885	437,040,099	49,151,894,469	1·057	112·46
1886	482,245,254	52,802,070,529	1·042	109·49
1887	552,074,752	61,561,069,996	1·034	111·51
1888	590,857,353	65,423,005,988	0·977	110·72
1889	619,137,237	68,604,012,396	0·976	110·80

The rates on iron ore, coal, limestone, and pig iron are probably not more than one-half of the average rate, because they are raw materials of the lowest class. This showing, which compares most favourably with the rates on European railways, is the more remarkable because it is accomplished in the face of a higher rate of wages, thus indicating that other elements besides wages paid enter into the determination of final cost, and must be taken into account by economists and law-makers when they deal with the subject. The principal factor, however, in producing this desirable result has undoubtedly been the use of steel rails, due to the genius of Bessemer. His contribution to American prosperity will form the subject of consideration in another place, but it would be less than justice if we failed to record here that among all the agencies which have produced the phenomenal development of the United States during the last ten years, there is none which approaches in importance to, or is so far-reaching in its influence as, the process which has enrolled the name of Sir Henry Bessemer among the great benefactors of mankind.

But when the materials, the men, the money, and the skill have been brought together, it still remains to secure such harmony of action between labour and capital as will ensure steadiness of employment and continuity of operations. The final answer to our inquiry as to the ability of the United States to supply the iron required for the continued progress of the country and the march of civilisation throughout the world depends, therefore, upon the establishment and maintenance of friendly relations between the employers and employed engaged in the work of production. Otherwise, it is quite conceivable that no considerable addition can be made to the present annual product. Indeed, this consideration throws much light upon the fact that Great Britain, with abundance of fuel and with access to adequate supplies of foreign ores, has not been able to maintain the product which was reached in 1882. We are thus brought face to face with the most serious problem of our age, because if we cannot increase our output, the growth of wealth, which now increases in a higher ratio than the increase of population, and is necessary to the amelioration of social conditions, must become stationary.

It cannot be denied that, throughout the world, the relations between capital and labour are far from satisfactory. They are undoubtedly undergoing a process of readjustment not unlike that which followed the abolition of serfdom at the close of the Middle Ages. During the process of evolution leading to a new era there must necessarily be unrest, agitation, sometimes violence, and generally severe loss on both sides, to the great detriment of society at large The solution, when it comes, must be based upon justice; and it cannot come until public opinion is definitely made up as to the rights and duties of the contending parties, or until the contention shall cease to exist by the voluntary action of the combatants. Meanwhile, the severity of the struggle may be greatly mitigated, and the final outcome accelerated, if certain fundamental principles which have been established by the experience of mankind are kept steadily in view, and rigorously applied as each new complication shall arise. While the propositions which I shall state may be disputed by extremists, I think they will be generally regarded as axioms ingrained in the very constitution of human nature, and therefore to be accepted as standards of right and wrong to which all contentions may be referred.

I. Individual liberty consists in the right of each person to control his own life, and to use the products of his labour in his own way, so long as he does not interfere with the equal rights of any other person.

II. Individual liberty implies the right of two or more persons to combine together and to use their property and faculties as they may see fit, so long as they do not interfere with the equal right of other individuals or combinations of individuals.

III. As population grows, there will necessarily be interference among individuals and combinations of individuals, which must be adjusted; and hence the necessity for government and for tribunals whose judgment must be final.

IV. In countries where law expresses the will of the majority, and in which it can be amended as often as the majority may desire, there is no justification for resort to private or personal force in order to rectify wrongs, correct abuses, and maintain the rights of men. If the courts of justice have not adequate jurisdiction, it is the duty of the Legislature, which represents the public will, to supply it, and all agitation should be directed to secure such legislation; and no man or set of men should be allowed to take the law into their own hands, to usurp the functions of the courts of justice, or to forestall the action of the Legislature.

Bearing these axioms in mind, the following conclusions may be submitted as incontrovertible:—

1. It is the equal right of employers and employés to make combinations among themselves, respectively, or with each other, to advance or reduce wages, or establish or resist legislation which either or both may regard as essential, desirable, or objectionable.

2. Neither party has the right to coerce the other into submission, except through the action of the courts or tribunals duly constituted to hear and decide upon causes of action submitted to them by either or both parties.

3. The right of workmen to refrain from labour and the right of the employer to cease to employ are correlative rights; but no one has the right to compel any other workman to cease from labour, nor has the employer any right to lock out his workmen in order to compel submission to obnoxious rules.

4. Strikes and lock-outs are therefore equally indefensible on the ground of justice, and can only be tolerated in the absence of provisions for the submission of grievances to the adjudication of competent tribunals.

5. No man has the right to compel another man to combine with him in any organisation, and when a man declines to combine, it is a violation of right to refuse to work with him, and to deny him the means of earning a living. It is equally wrong for employers to black-list men, so that others will not give them employment.

6. A boycott cannot be defended under any circumstances whatever. It is, in effect, a declaration of private war, which is a crime of the Hatfield-McCoy class, to be stamped out by prompt and severe punishment.

7. The claim of any body of men that under any circumstances they have the right to stop the operations of business by the issue of an order in the name of organised labour or associated capital cannot be tolerated. When such an order is given in regard to any railway or any other means of communication, it is a direct assault upon the common weal; and the failure to arrest and punish the offenders thus usurping the executive functions of the State and the judicial power of the courts, is proof of cowardice on the part of the public officials, and of degeneracy in that public opinion which excuses or permits the

violation of the principle of the common law, that "not even the king can obstruct the highway."

And yet we live in a country and under a government professedly of law founded upon public opinion, in which all these abuses go unpunished. If they continue, disorders will increase, and capital will retire from business subject to such outrage and disturbance.

The iron business, as now organised, is a field in which capital and labour are brought into direct and immediate contact. It requires the capital of at least one thousand dollars for each man employed. It has grown up under the wages system, in which one party hires the other at an agreed price, and all the risks and profits of the business are assumed by the owners. Under the modern system of industry, its operations are conducted on a scale of such magnitude as to require the association of capital in corporate organisations, which have almost entirely superseded private firms and ordinary partnerships.

As a rule, the workmen have formed unions for the care of their interests, and especially to secure a satisfactory rate of wages. The formation of such unions is alike a right and a duty; and so long as they confine themselves to the assertion of the rights and the care of the interests of their members, they are to be commended and encouraged. The employers, on the other hand, have also various associations for the protection of their own commercial interests, but no general organisation, so far as I am informed, for the regulation of wages. Both sides are now prepared for argument; and in this fact is to be found the starting-point from which may be readily reached the ground of conciliation and arbitration which ought to make strikes and lock-outs a memory of the past, to be recalled as a warning, and not as a menace. In England, which has taught us how to make iron and steel cheaply and well, the system of voluntary arbitration has been in operation since 1869, and has worked, in the main, in a manner satisfactory to both parties, and with decided advantage to the public. Official arbitration, under the law which was passed in 1872, has not been found to be acceptable to either workmen or employers; and no case has ever arisen under the provisions of the law from which enthusiasts expected the most beneficial results. On the other hand, too much is not expected or attempted in the voluntary arbitrations which have sufficed to settle most of the disputes of the last twenty years.

It is admitted that the question of wages is fundamental, and that it can only be solved by the equal representation of both sides, with an umpire, whose decision shall be final, after the fullest submission and discussion of complete information as to costs, sales, and the condition of the trade. Attempts of either side to get the better of the other by tricks and misrepresentation have long since ceased, so that when a result is arrived at, the award of the arbitrator is accepted by both sides as a satisfactory solution. Here it is obvious that three fundamental elements of conciliation have been evolved from the contentions which formerly resulted in strikes and lock-outs. The right of combination on both sides is admitted, the mutual equality of both parties is conceded, and the right of both to be informed as to the actual condition of the business is acknowledged.

In view of such an example, and of the advantage of avoiding conflicts damaging alike to employers and employed, I am satisfied that we shall not be long in adopting a similar system of settling disputes by voluntary action, and that there will not be any disturbances serious enough to interfere with the rapid increase of product, which, as we have seen, is required by the progress of our country.

It is manifest that this method of settlement involves publicity as to the profits of business. There is undoubtedly great reluctance and some ground of objection to the disclosure of cost and profits; but as a matter of fact, the transfer of business to large corporations has really made this information public property, and in the iron business there is no longer any pretence of concealment either from stockholders or competitors. Surely, then, there remains no valid reason for denying to the workmen the information necessary to enable them to formulate reasonable demands; and it is to the interest of the owners to give this information, inasmuch as the margin of profit on manufacturing operations is now narrowed down to the smallest limits consistent with a moderate return on the capital employed. There is so much misapprehension on this point in the public mind that I am impelled to say that, in the great staples of trade, it is exceedingly difficult to get an adequate return for the capital employed, and the business is often conducted for long continued periods on a basis which ensures only wages for labour, without any return whatever for capital. Where large profits are realised, they are due either to the production of specialities covered by patents, or to the possession of raw material under exceedingly favourable conditions of cost or locality.

There is no feature in the business more pronounced than the excessive competition which cuts down profits to a minimum, and hence attempts have been made to control product and prices through combinations looking to the maintenance of standard prices, and, in some cases, by the reduction of the output. In the public mind such arrangements are confounded with trusts, which have been the subject of so much recent criticism and denunciation. The objection to trusts is not to be found in the magnitude of their operations. This, in the modern development of industry, is unavoidable, and constitutes, in fact, an advantage to society by ensuring lower prices and better quality, and to the workmen by providing the best appliances for labour and arrangements for the preservation of health and the increase of comfort. It is only when trusts attempt to create a monopoly and succeed in destroying competition that they become injurious to the public welfare. It is extremely doubtful whether it is possible to maintain in this country an effective monopoly of any staple product of industry; but whether possible or not in other branches, the iron business is too widely diffused and is too vast in extent to admit any monopoly not sanctioned by law. The concentration of business, however, in special localities, and the consolidation of interests in order to secure enactment of administration, is a public benefit. The greater the organisation, and the larger the capital employed, the more certain it becomes that the business will be steadily prosecuted, thus avoiding the greatest evil under which workmen suffer —lack of constant employment. The principle of association developed in great industrial corporations is therefore altogether beneficial, and should have the hearty sympathy of the public, and especially of the labour organisations.

In any previous period of history such vast establishments might have been converted into devices for oppressing the workman and for preying upon society by excessive prices; but in the presence of powerful labour organisations, whose right to demand information, and whose power to obtain justice, are now conceded, no oppression is possible, and no exaction can be continued under the scrutiny of an omnipresent and omniscient journalism. Society has, therefore, nothing to fear from the growing tendency of workmen to form unions, and of capital to centralisation in great industrial corporations. But society has a duty to perform in the enactment of legislation which will regulate these organisations by a clear definition of their respective rights and duties.

Publicity, inspection, and discussion are the great safeguards which the public can apply in order to correct abuses and avoid conflicts and disastrous losses. The discouraging feature of the time is that the legislative department has shown, not merely indifference, but abject cowardice, in dealing with the questions which from time to time require the interpretation of the law. Some of the legislation which has been recently enacted is a positive violation of the fundamental axioms which I have ventured to lay down, and of the provisions of the Constitution in reference to the liberties of the citizens, which are quoted in the outset of this address; but the greatest evil is the failure to legislate at all with reference to interferences which result in constant conflict, to the great injury of the public. What we need, therefore, is a recurrence to the well-settled principles of jurisprudence, a higher order of statesmanship, and the courage on the part of our public men to stand up for the right, though for the time it may involve the sacrifice of personal popularity.

The course of procedure is clear. All organisations which avail themselves of the provisions of the law for the creation of corporations, should be required to report the result of their business, and be open to the inspection and scrutiny of public officers appointed for the purpose. This principle is already recognised and enforced with reference to savings and other banks, insurance and trust companies, and railway corporations. It has not yet been applied to industrial organisations; but these now exist on so large a scale, and employ so many men—disputes with whom affect the public convenience and interests so seriously—that every safeguard should be applied to prevent the disturbance and dislocation of industry. Publicity as to profits and losses would at once remove the most serious cause of strikes, which often take place when it is impossible for the employer to concede the demands of his men, because his profits will not warrant the concession. With proper information, the intelligence of the workman may be relied upon not to make an issue which can only result in failure.

It will not be necessary to give any compulsory power of rectification to the officers charged with the duty of inspection. No real abuses can survive the criticism of the press when they have been fully investigated by an impartial tribunal. No strike can then succeed unless it is based upon an abuse recognised and reported as a positive grievance by competent authority. All trade regulations, and the rate of wages, can then be safely left to voluntary agreement between the representatives of masters and men, sitting as equals on a board of conciliation, and presided over by an arbitrator who has the confidence of both.

Violations of the fundamental principles of society should be made crimes to be promptly punished. The Legislature will readily respond to sound public sentiment in this respect, and a stern enforcement of the law is the best security for peace and order.

With industry under the control of great corporations, endowed with adequate capital; with the workmen thoroughly organised to protect their rights and advance their interests; with proper public inspection and publicity as to the condition and results of the business; with legislation covering the grounds of conflict; and with the co-operation of the judicial arm clearly expounding and steadily enforcing the law, it does not seem difficult to forecast the outcome of the evolution which is going on in the industrial world, and which seems to be full of promise and encouragement under the beneficent law which Edward Atkinson discovered, and which he and Robert Giffen have demonstrated, to wit, that labour is receiving a steadily-increasing share of a steadily-increasing product; and that capital is receiving a steadily-diminishing share of an increasing product, still ensuring for it an adequate remuneration.

More than fifty years ago, John Stuart Mill laid down the proposition that when employers and employés had a common interest in the work, in the nature of a partnership, the means would exist of "healing the widening and embittering feud between the class of employés and the class of capitalists." Since these words were written the feud has widened and the conflicts have become more frequent and more intense. On the other hand, the work of educating both employers and workmen has been going on in a bitter school of experience. Various attempts have been made to get the two classes together on some basis of organisation which will make the remuneration of each directly and visibly dependent upon the profits of business. Under the existing system, wages are necessarily paid out of profits in the last analysis, but the rate and amount are not determined by the actual results from day to day. On the other hand, they constitute a prior lien upon the business, as well from necessity as now by law, and are thus exempt and guaranteed against the losses of the business.

The workman, however, fails to perceive that he is thus dependent upon the profits in order to get wages, and that he has the preference over all other claims upon the product of the business. Hence the sense of personal interest is lacking, and the success of the enterprise forms no part of the workman's current of thought. He has, in fact, no means of knowing the condition of the business, and his individuality is lost in the vast aggregation of energy which is combined in order to produce the results of modern industry. In England, it is notorious that the action of the trade-unions has been exerted in the direction of obliterating the individual to such an extent that special skill is rapidly declining, and in the finer grades of work it is almost impossible to find the experience required for the production of instruments of precision. This is a national evil of the first magnitude, and its disastrous consequences are becoming more apparent to the intelligent workman, whose opportunities to rise in life are thus abridged and destroyed.

Slowly but surely, therefore, a new idea has been taking root in the industrial mind. Profit-sharing is getting to be a familiar thought both with employers and workmen, and many promising experiments in this direction are now in progress in this and other countries. This practice is to pay the current rate of wages in the usual manner, then to allow a reasonable percentage on the capital employed, and, if there be any excess after these payments, to divide it equally or otherwise between the capital and the labour, estimated by the amount of wages paid. The success of this system depends obviously upon the ability of the business to earn the current rate of wages. As this is not possible at all times, the employer must have sufficient capital to carry on business at a loss for a season, with the expectation of recouping the loss out of the future profits. It is idle to expect that workmen will be able or willing to refund losses, the risk of which must remain, therefore, as it now does, with the employer. Hence the necessity and usefulness of the great organisations, under the control of which the iron business is passing by steady and irresistible progress. In such establishments the work of production will go on in bad as well as in good times, and the workmen will be secured against the evils of intermittent employment.

But even this advantage is not sufficient for intelligent and ambitious men. Each man should be paid wages according to the value of his labour, and not on the mistaken basis of a dead level of mediocrity, advocated and enforced by some trade organisations. Progress is only possible where the individual is encouraged to develop his skill and apply his labour by a payment in proportion to the results achieved. But higher and beyond all this stands the stimulus of being engaged in a successful business, and having a direct interest in its results. If the workman were a stockholder as well as a labourer working for wages, he would have such an interest; and this would tend to raise his self-respect as well as to develop his energies. But profit-sharing, as it is called, will never be popular with the workmen, because, on the face of it, it is an act of grace from the employer.

A self-respecting workman is not willing to accept charity. What he wants is justice; and any concession from the employer which does not recognise the right of the workmen will be, and ought to be, rejected by independent and self-respecting men. When a workman, however, becomes a shareholder, either by payment for stock, or by an agreement to pay for it out of his earnings, he stands on a level with the capitalist, and in fact, as well as in theory, is in a position to feel that he is working for himself in doing his best to promote the success of the business in which he is engaged.

It should be a matter of congratulation, therefore, that the formation of trade-unions, contemporaneously with the rapid growth of large corporations whose stock is divided into such small shares as to admit of easy distribution, clears the way for the new era when every self-respecting workman will insist upon being an owner, and every well-managed corporation will see that its workmen are directly interested in the results of the business. To effect this desirable end, no compulsory legislation, and no addition to the powers of corporations, are needed. The educational influence of the conflicts which have occurred has already done much, and the conferences which frequently took place as to wages and regulations are doing more, to establish a better understanding, to create harmonious action, and to develop the idea that business cannot be carried on unless both the capital and the labour employed share directly in the proceeds. The two classes are organised, as it were, into armies of observation, and occasionally they come into conflict, but the chances of collision are becoming daily smaller, and will disappear altogether when their differences are merged in a sense of common ownership, through the agency of corporations, admitting and cultivating the direct participation of the workmen in the profits.

It is, however, by no means necessary that all workmen should thus become shareholders. There will always be a considerable element of an unstable and unintelligent character, whose participation in the ownership is neither desirable nor possible; but I think the time is near when it will be discreditable to a workman not to be also an owner in the establishment in which he works, and that all workmen of the better class will have such an interest. It is quite conceivable that the workmen may ultimately acquire the preponderating interest, in which case the best possible solution will have been reached, in which labour hires capital at the lowest possible rate, and thus becomes the main factor in the conduct of industry. This process can only succeed in establishments which have all the elements of success in the way of location and the possession of raw materials, and of appliances for work. But such corporations, in the iron business at least, are so numerous as to offer abundant opportunity for the inauguration and successful application of this beneficent policy. I am glad to say that one of the greatest of our organisations, recently formed by the consolidation of several large establishments most favourably situated in all respects, the Illinois Steel Company, has made a promising beginning in the direction of interesting its workmen in its business. The outcome of this experiment will be watched with very great interest; and it may be commended to the attention of our guests as the most important and encouraging feature of our wonderful development, because it shows how the concentration of force under one management, in accordance with the modern tendency to centralisation, may be made to solve, and must necessarily solve, the problem of harmonising capital and labour engaged in the work of production, without new legislation, or the application of any other than familiar and well-recognised principles of social organisation.

The points which I desire to enforce by these arguments are:—

First, That the industrial world has been steadily moving during the present century in the right direction for the welfare of mankind, and that the disturbances which have occurred have been necessary incidents of a beneficent evolution in the steady advance in the wages of labour, and in the distribution of the proceeds of industry upon the basis of equality and justice.

Second, That it is not necessary to invoke any new principles of government, or to inaugurate any revolution, in order that capital and labour may be associated together in peace and harmony. Progress is rather to be sought in diffusing a knowledge of the principles upon which government is founded, and by appropriate legislation framed in accordance therewith to meet the necessities of the complex relations arising out of advancing civilisation and the unprecedented increase of riches in our day. A rigid enforcement of the laws thus formed is the necessary and sole condition for the maintenance of progress, peace, and order.

Third, That the time is approaching when capitalists and labourers will more and more be joint-owners in the instruments of production—that while the wages system will necessarily survive, the workmen will, to a large extent, become their own employers, and finally may hire capital as capital now hires labour. The facilities offered for the division of property, through the distribution of corporate shares, will lessen strife, develop skill, reduce cost, increase production, and promote the equitable distribution of wealth, which, it must never be forgotten, is the chief end of the social organisation.

Fourth, That the invasion of government into the domain of industry must be met with uncompromising opposition. The proper function of government is supervision, regulation, and adjudication. The work of production and distribution belongs to the citizen. Any departure from this principle must result in the ruin of free government and in the substitution of despotism, the characteristics of which are communism, anarchism, and nihilism.

Our contract labour law is an example of the pernicious character of such interference. It affords probably the only instance in history, since the expulsion of the Huguenots from France, in which the Government has deliberately decided to deprive itself of the highest order of skill, by refusing to admit trained workmen, although it is still willing to receive ignorant and incompetent immigrants. If this law had been enforced fifty years ago, David Thomas, the first President of this Institute, whose advent to the United States has added untold millions to its wealth, would never have seen our shores. Read the contract under which this benefactor of our trade was induced to leave his home, and contrast it with the provisions of the law which fetters industry and deprives us of trained and useful citizens.

"Memorandum of agreement, made the thirty-first day of December 1838, between Erskine Hazard for the Lehigh Crane Iron Company of the one part, and David Thomas, of Castel Ddu, of the other part.

"1. The said Thomas agrees to remove with his family to the works to be established by the said Company on or near the river Lehigh, and there to undertake the erection of a blast furnace for the smelting of iron with anthracite coal and the working of the said furnace as furnace manager, also to give his assistance in finding mines of iron ore, fire-clay, and other materials suitable for carrying on iron-works, and generally to give his best knowledge and services to the said Company in the prosecution of the iron business in such manner as will best promote their interests, for the term of five years from the time of his arrival in America, provided the experiment of smelting iron with anthracite coal should be successful there.

"2. The said Hazard, for the said Company, agrees to pay the expenses of the said Thomas and his family from his present residence to the works above-mentioned on the Lehigh, and there to furnish him with a house and coal for fuel, also to pay him a salary at the rate of two hundred pounds sterling a year from the time of his stipend ceasing in his present employment until the first furnace on the Lehigh is got into blast with anthracite coal and making good iron, and after that at the rate of two hundred and fifty pounds sterling a year until a second furnace is put into operation successfully, when fifty pounds sterling shall be added to his annual salary, and also fifty pounds sterling per annum additional for each additional furnace which may be put into operation under his management.

"3. It is mutually agreed between the parties that should the said Thomas fail of putting a furnace into successful operation with anthracite coal, that in that case the present agreement shall be void, and the said Company shall then pay the said Thomas a sum equivalent to the expense of removing himself and family from the Lehigh to their present residence.

"4. In settling the salary, four shillings and sixpence sterling are to be estimated as equal to one dollar.

"In witness whereof the said parties have interchangeably set their hands and seals the date above written.

"Witness: ERSKINE HAZARD, [SEAL]
For Lehigh Crane Iron Company.

DAVID THOMAS. [SEAL]."

But in condemning the interference of the Government in the actual work of production or distribution, let me guard against the inference that I am not in sympathy with the modern tendency of legislation to ameliorate the condition of the labouring class by suitable regulations of the hours of labour, by securing elementary and technical education, by improving the dwellings and providing for the general recreation of the masses. Neither do I object to the control by the Government of all functions which are of a general nature, such as the transmission of letters, and the care of the public health. But even in these cases the general Government should confine itself to administration and regulation, employing as far as possible the agencies provided by private enterprise.

The general tendency of the age is, however, in the right direction, and it cannot be arrested by a few temporary violations of sound statesmanship. The remedy will speedily be found when the workmen generally shall acquire a direct interest in the great industrial organisations of our day; and it is to this result that all intelligent and patriotic men should direct their efforts. The very simplicity of the plan may suggest doubts as to its efficacy, but all doubt will vanish, I am sure, if in our trade the proprietors and managers shall make an earnest effort to interest the workmen in the ownership of the property by making it easy for them to acquire shares upon the same terms as they can be purchased by capitalists. So certain am I of the disappearance of all strife when this diffusion of ownership shall become general, that I have been impelled to ask for this subject the thoughtful consideration of the representatives of the iron and steel industry of the world, now for the first time assembled in the country where the final development of this business must take place upon a scale of unprecedented grandeur.

If I have ventured to give an exceptional and unusual direction to this address, it is because I am fully persuaded that the conflict between capital and labour cannot go on without impeding, and finally paralysing, the operations of the industrial world, and interrupting the continued progress of society in wealth, comfort, and civilisation. The present century, now nearing its close, has been pre-eminently an era of invention and of development in the forces of Nature, enriching society and opening possibilities of general culture beyond the dreams of enthusiasm. Industrial peace is, however, necessary to the fruition of the hopes of a better adjustment of social relations, and of progress which will remove all privilege and all artificial impediments to the final establishment of equal rights. It is encouraging to think that this result can be reached without seeking for any new principles of government or introducing any new methods of legislation. *Natura viam monstrat.* We have no more reason to fear association than we have to dread competition, for they are the necessary and inseparable factors of progress. They are the agencies which have transformed the face of society during the present century. They are only in the infancy of their power, and no man can measure their potency in overcoming the evils which survive or which have been incidentally occasioned in the application of the natural forces in new directions. If we are careful to secure the maintenance and the application of individual energy, we have nothing to fear from association and combination. Participation in the ownership of the instruments of production and the agencies of distribution, rendered possible through the subdivision of the shares of the great corporations which control the domain of industry, will give the workmen who are employed in their conduct full scope for individual energy and the development of special skill in every department. The general distribution of shares is, therefore, to be encouraged as the true solution of the conflict between capital and labour, and may be relied upon to bring peace out of contention without resorting to the exasperating fallacies of communism, or the dangerous tendencies of class legislation, or to governmental interference with industrial pursuits.

In another part of this volume will be found a series of diagrams—reduced and engraved from a large chart, shown at Chickering Hall during the Institute meetings—which illustrate by graphic methods the recent progress of the world, and of the several leading countries, in the production of coal, iron, and steel, and the relation which this development bears to increase of wealth and population, to the course of prices, and to the productiveness of land.—Ed. *Journal.*

THE HOLLEY MEMORIAL.

INAUGURAL ADDRESS BY MR. JAMES DREDGE.

A MEMORIAL which had been erected to perpetuate the memory of the late **ALEXANDER LYMAN HOLLEY**, member of the Iron and Steel Institute, was unveiled in New York on the afternoon of Thursday, the 2nd of October, by MR. **JAMES DREDGE** (one of the editors of *Engineering*, London), who also, previous to performing that ceremony, delivered in the Chickering Hall an interesting memorial address, an abridgment of which is contained in the following pages:—

Mr. **DREDGE** commenced his address by reading two letters—one from Mr. James Forrest, Secretary to the Institution of Civil Engineers, London, who bore testimony to "the eminent degree in which the late Mr. Holley's work, and his repeated visits to this country, assisted in bringing about, and in establishing upon an enduring basis, the cordial understanding which so happily exists between the great engineering professions of the United States and the mother country;" and the other from Sir Henry Bessemer, which was as follows:—

"DENMARK HILL, SURREY, *August* 1, 1890.

"DEAR MR. DREDGE,—The Engineers of the United States having done you the honour to invite you to New York for the purpose of unveiling the statue of your old and esteemed friend, Alexander L. Holley, it has occurred to me that this occasion presents an opportunity of which, with your kind permission, I am most anxious to avail myself.

"You are aware that the Civil, Mechanical, and Mining Engineers of America have invited the members of the Iron and Steel Institute to visit their country, and, with more than their usual generous hospitality, have provided a most interesting and extensive programme for their mental and physical enjoyment.

"It is a source of very great regret and disappointment to me that Nature has interposed an insuperable barrier between us, by giving me a constitution that does not permit me to make the shortest sea-voyage without absolute danger to life; but for this circumstance, the fact of my being in my seventy-eighth year would not have prevented me from accepting their generous hospitality, and seeing with my own eyes the enormous progress which the indomitable energy and perseverance of the citizens of the New World have made within the last twenty years.

"Much as I should have felt interested and impressed with their great mechanical and engineering progress, I should have experienced still greater pleasure and pride in visiting their magnificent steel-works and seeing the material that bears my name produced on a scale of greater magnitude than it is in any other country in the world. And when I reflect on the great honour conferred on me by this appreciation of my labours, I find it difficult to express the gratification it has afforded me.

"In England, France, and Germany many generous tributes have been accorded me; by imperial personages, corporate bodies, and scientific institutions. From the nature of her constitution, America has no orders of knighthood or other titles to bestow. But to a generous people a way may always be found of honouring those whom they desire to honour, and in giving the name of Bessemer to a rising city in the United States, they have created a living monument to my memory that will last for centuries after all the titles and medals I have received in Europe have passed away and been forgotten. It is in vain I look for words adequately to express my gratitude for this great memorial, but I gladly avail myself of this opportunity of thanking them, though but very feebly, for the honour done me, which far exceeds in generosity and value anything that my invention deserves.

"It has been suggested to me that the Society of Mechanical Engineers of America would still further honour me by accepting my portrait; this I now send you, and I beg you to present it to them in my name, and at the same time to express the gratification its acceptance will afford me. Thanking you in advance for the trouble I am giving you, I remain, dear Mr. Dredge, yours faithfully,

HENRY BESSEMER."

. . . . The course of Alexander Holley's early years and education resembled those of most other well-born youths of the same period. He was the offspring of a union between the representatives of two old New England families that had taken root and flourished for many generations in Connecticut since they were transplanted from English soil. Deprived, almost from the day he saw the light, of a mother's care, he was fortunate enough to have that want supplied by the second marriage of his father, and the influences of the simple, rigid, and God-fearing domestic circle in which his earliest years were passed, nourished the noble impulses and high principles that were born in him, and strengthened them so that they remained with him through life. He passed from the little district school to the local academy in Salisbury, thence to another in Farmington; from Farmington to Stockbridge, and from Stockbridge to Bridgeport, that he might prepare for Yale College. He did not commence his college career until 1850, when he was eighteen years old, so that his education, which had been carefully superintended by his father, was more than usually thorough and complete. Yale College did not have the honour of inscribing his name upon her books, because in 1850 the Brown University at Providence had founded a scientific chair, and it was determined that Holley should go there instead of to New Haven. After three years of college, Holley was well fitted to commence the battle of life. Twenty-one years of age, wondrously winning in manners and appearance, with a fine constitution and indomitable energy, he was indeed well adapted physically for the struggle. And still more so intellectually. The strong natural bent of his character had been carefully strengthened and trained by himself from very early years. The influences of home were deeply rooted; his powerful memory and almost limitless capacity for observation had been developed by habitual and constant use. By nature he was an excellent draughtsman, and also by nature he had the power of language; hence from a very early age he had a facile and rapid pencil, a keen and eloquent tongue. He was a leader in youthful debate, an acknowledged chief in college journalism. The boy was father to the man, and the engineering instinct, strong within him, had shown itself almost from the first dawn of his intelligence. Mechanics, the design of machinery, and especially everything that had to do with locomotive engineering, gradually took the first place in his mind, almost to the exclusion of collegiate subjects, and he made his start in the world in the shops of Messrs. Corliss & Nightingale, at Providence; there he served with credit as draughtsman, mechanic, engine-driver, and inventor, and it is a remarkable testimony to his great ability at that time that, without any special preliminary technical training, Messrs. Corliss & Nightingale parted from him regretfully, and at his own wish, because he preferred to devote himself to locomotive design and construction rather than to that of stationary engines. With only eighteen months' practical experience, Holley started out in search of employment in locomotive works. It was natural enough for him to meet with failure and disappointment; after about a month he fell into despair. "I am ready to sink," he said, "for if there is anything certain in this world, it is that I will never do anything but just this one thing, namely, build locomotives." Soon fate was kind, and found employment for him in the locomotive works of Jersey City, where he remained long enough to gain valuable practical experience and to convince all those about him of his great ability and energy. But his dream of always building locomotives for a living was to be a short one.

A young man of his own age and of brilliant genius had, while Holley was receiving his education, raised himself from the menial life of a farmer's boy to that of the superintendent of the New Jersey locomotive works, and had quitted it before Holley had found the situation he was so anxiously seeking. Without education, this man had already come to the front as engineer and author; at fifteen years of age he had secured publication for a series of "Monthly Mechanical Tracts," which he issued at Lowell in 1847. Humble as was his origin, his uncle had, years before his birth, brought the name he was to bear into notoriety, and the famous calculating boy, Zerah Colburn, was the object of wonder in scientific circles both in Europe and America Beyond a natural gift of rapid calculation the uncle possessed no marked ability, whilst the nephew, less endowed as a mathematician, was in other respects probably the most marvellous member of the engineering profession of any country. A writer on mechanics at the age of fifteen, the superintendent of an important locomotive works at twenty—and this without any technical training except what could be gathered whilst he laboured for his scanty living—Zerah Colburn at twenty-one commenced the career for which he was best adapted, and became editor of the mechanical department of the *American Railroad Journal* in 1852. Of course he soon abandoned this position, and the following year undertook as his own property the *New York Railroad Gazette.* He was pushing the fortunes of this venture with that ferocious energy characteristic of the man, at the time when Holley obtained the situation he had been seeking; doubtless the chief talk in the works was of the late superintendent's newspaper, and we may be certain that Colburn was often at the locomotive shops, getting information and seeking new subscribers. It seems but a poor little sheet now, that *New York Railroad Gazette*, for technical journalism has kept well to the front with the rapid and triumphant forward march of the engineer; but to me those flimsy pages are full of the deepest interest from their being the first effort of a man who was certainly the ablest technical journalist we have ever seen. So it was through the means of this paper that Holley and Colburn first met, and for some years they were destined to tread together the upward path to fame.

I have said that the most boyish letters and essays of Holley showed gleams of literary talent, which time and education kindled into a bright flame. In many respects the tastes, aims, and ambitions of the two young men were similar. Holley had already realised the pleasure of seeing his work in print and of being paid for that work; when he was eighteen years of age he had written quite a remarkable treatise on cutlery, which had appeared in *Poor's Railway Journal* in 1850. It followed, as a matter of course, that he was as eager to write for Colburn's *Gazette* as Colburn was to obtain the assistance of such a congenial contributor. So in a short time the relations between the two drew closer, and Holley and Colburn entered into partnership, editing the little sheet conjointly. It was not long before a marked success attended their efforts; then Colburn wearied of the work, and in 1856 sold his share to Holley, and emigrated to Iowa, where he bought land with the proceeds of the sale, in obedience apparently to some passing fancy that prompted him for the moment to turn his hand to farming. For a year longer the paper, under the changed name of *Holley's Railroad Advocate*, did fairly well; the new proprietor bore the business and editorial burden of the undertaking more systematically than Colburn, I am sure, but not with the same degree of feverish energy which Colburn always brought for a time into every new scheme he took in hand. In 1857 a great wave of commercial disaster swept over the country and engulfed the *Railroad Advocate*. Colburn had wearied of Iowa, and returned to New York, where he and Holley, on the ruins of the paper, started another journalistic venture which lived for two or three months as *Holley and Colburn's American Engineer*. Brief and unsatisfactory as these experiments in journalism had been, they nevertheless were attended with the most useful and important results to both men. They had lived by their pens for two years, which was no small matter; they had gained a vast amount of experience of a varied character; they had of necessity come in contact with many engineers; and their writings had been sufficiently original and striking to attract much attention. The experience had, in fact, prepared them for their next venture, one which was destined to sever permanently the connection between the two men, and to open out for each new paths in widely diverging directions. The hard times of 1857 had absorbed what little money they possessed, but they could claim to be the owners of a more important capital—the confidence of many men of influence and means. It was notorious that at that time the construction and management of American railroads were in a deplorably backward condition compared with those of Europe, and the brilliant idea occurred to Holley and Colburn to get themselves made delegates of some of the principal railway companies in the United States; to travel over Europe, and to collect information on the railway practice of the Old World which should be made useful for the improvement and perfection of railroads at home. To secure the patronage and assistance of many influential persons was a work of no great difficulty, and in the summer of 1857 they commenced their first voyage across the Atlantic, a voyage which was destined to bear immediate fruit, and to lay the foundation for their brilliant, and, alas! too brief careers.

Can you not picture to yourselves these two young men as they started upon their first and fateful voyage; full of generous enthusiasm, overflowing with life, and with the vigour that is born of intellectual power? Their early training was completed; their experience already wide; their powers of reception almost infinite. You can imagine that their high ambition, if it was vague, was as unbounded, as they felt the power within them was of achieving it. How great their energy was, the result of the few weeks' visit to Europe on that occasion still bears testimony in the large volume they completed on the "Permanent Way and Coal-Burning Boilers of European Railways." They were of an age when they could afford to burn the candle at both ends; and they did, under forced draught. In a memorandum by Zerah Colburn, now in my possession, I find the following reference to this book. "In 1857–1858 I wrote the large work entitled the 'Permanent Way and Coal-Burning Boilers of the European Railways,' Mr. Holley's name appearing as joint author, in consideration of our sharing the cost of the undertaking, but more especially because of the assistance rendered by him in collecting information and preparing drawings." Those who can read between the lines of this memorandum, will understand how large Holley's part was in the preparation of this book.

At that time Mr. Daniel Kinnear Clark had attained a considerable reputation both in England and in America by his very excellent book on "Railway Machinery," and it followed, almost as a matter of course, that he was the first person in London sought out by Holley and Colburn when they arrived in 1857. At that time I was a boy in Mr. Clark's office. I, like Holley, but in a very humble way, had been seeking despairingly for work, and a kind fate had placed me with Mr. Clark in the summer of 1857. I never can recall without the deepest thankfulness the mysterious working of Providence which, apparently by the merest accident, brought me in contact with those two men.

It happened that they, coming direct to London, had gone straight to the office of Mr. Clark, where I was alone, and thus I was the first person to shake hands with Holley on his arrival. Twenty-five years later I was the last Englishman to shake him by the hand in London, when we said our final farewell. You cannot imagine the effect which the sudden apparition of the two young Americans in the gloomy London office had upon me. They appeared to me like beings from a superior world, so unlike were they to any persons I had ever met before. Even with my untutored and crude power of perception, I could feel that they were surrounded with an atmosphere of energy and intelligence; that they were overflowing with vitality. The one seemed to me a spirit of darkness, the other a spirit of light, and both so immeasurably my superiors, that I could do little more than gaze on them in wonder. Who could at that time have supposed that the influence of these two men was to be made, under Providence, to change and fashion my whole career; that they were to show me the path to a future infinitely brighter and higher than I could then have planned in my most sanguine dreams? Yet so it was to be. Why they should even then have felt an interest in one so ignorant as myself, has always been a source of wonder to me. I suppose there must have been some mysterious and inexplicable bond of sympathy. I know that they exercised a strange influence over me; that without my knowing it, they widened and strengthened my mind; that I absorbed much knowledge from them. When their brief visit came to an end, and they returned to New York, most of the light went out of my life, though their influence remained behind, especially that of Holley, whose bright individuality rested with me as an ideal, which I might perchance, with time and constant effort, feebly imitate. The following year Zerah Colburn returned to London alone; he became the editor of *The Engineer*, and I, having sought him out, had the privilege of being closely and intimately associated with him until the curtain fell upon his tragic end. As no doubt you know, after he returned to England in 1858, he made his permanent home there, with the exception of a few months in 1860, which he passed in Philadelphia. You are also aware that it was he who founded the London *Engineering* in 1866; into the management of this journal he threw, for the first three years, the whole force of his great erratic powers. After their first visit to London, and their joint publication of the volume on European railways, Holley and Colburn, without becoming actually estranged, had but little in common. The dark and fiery genius of the one was, in fact, so opposed to the trained talents and noble soul of the other, that it was impossible for any real and lasting sympathy to exist between them.

With Holley's return to America in 1858, or shortly afterwards, commenced the journalistic epoch of his career. For some years he was a valuable and industrious contributor to the *New York Times*, and certainly never before or since has any daily newspaper been so fortunate in the services of an engineering contributor. In 1859, and again in 1860, he visited England, chiefly to write upon a subject which was then attracting the attention of the civilised world—the *Great Eastern*. This business brought him into intimate contact with the engineers of that vessel, Brunel and Scott Russell; with the last-named the acquaintance ripened into a warm personal friendship which always remained. The *New York Times*, the *Railway Review*, inventions connected with the steam-engine and permanent way, and miscellaneous literary employment, kept Holley closely occupied, and brought him plenty of reputation, though but little money, until the War of Secession. It is needless to say that Holley, like a good patriot, offered his able services to the Government, and it is interesting to add that his offers were uniformly declined. It was during this great national crisis that Holley, while still holding on to his main support—a brilliant and facile pen—had the opportunity of taking up work more congenial to him. He was employed by Mr. Stevens in 1862 to visit Europe in order to obtain information that might be useful in the construction of the Stevens' battery, on which so much time and money, as well as skill, were wasted. Mr. Scott Russell, who at that time had considerable interest in naval and military circles, rendered Holley good service in obtaining for him introductions and information, while his own presence of mind and coolness often stood him in good stead in obtaining access to places the official doors of which were closed against him. It was this new connection that turned his mind to the production of that important hand-book on "Ordnance and Armour," which, when completed, was destined to remain for so many years the standard book of reference on the subject.

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The practical value of the Bessemer process for manufacturing steel had by this time become widely recognised, and it followed almost as a matter of course that Holley, who was always on the look-out for some new and good thing, felt intuitively that the time for which he had so long waited had at last arrived. The story of the Bessemer process was at that time no new one. Seven years before, at the Cheltenham meeting of the British Association for the Advancement of Science, Mr. Bessemer had made the first public announcement of his invention. The title of the paper excited derision;* its reading, wild enthusiasm. Mr. James Nasmyth said of the samples shown to the astonished audience, "Here are true British nuggets." A wave of excitement passed over the country; one result of this paper was that almost immediately a sum of 250,000 dollars was offered for the English patents; another, that within a month £28,000 had been paid for licenses to work the process in Great Britain alone. Then swiftly followed a fierce reaction, consequent on failures due to hasty experiments and crude trials. Abuse of the inventor was as hearty as the praise had been fulsome a few weeks before.

The newspapers of the day were unanimous in condemning the process as delusive and useless, and referred to it as "a brilliant meteor that had flitted across the metallurgical horizon, dazzling all beholders for a moment, only to die out and leave no trace behind." As a lasting tribute to the sagacity of the Council of the British Association, I may add that that astute body refused to admit the paper in their published Transactions. In the face of terrible difficulties and discouragements, Mr. Bessemer worked steadily on, and in the course of a few years he established works at Sheffield, where the process was still in an experimental stage when Holley first visited them.

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* On the Manufacture of Malleable Iron and Steel without Fuel, read August 13, 1856.

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The Sheffield Bessemer Works in 1864 were on a very small scale; they only comprised two 3-ton converters and a corresponding plant. Holley came from America upon this business as the representative of Messrs. Corning, Winslow, & Co., a firm that was afterwards changed to Winslow, Griswold, & Holley. His mission was to purchase the Bessemer patents for the United States; to learn the process, and afterwards to inaugurate the new industry at home. As he said, that journey was no pleasure trip; but he came back successful on all points, and the following year the works at Troy were built.

As is the case with so many great inventions, a number of active minds were turned towards the manufacture of steel, stimulated thereto by Bessemer's success, and his reputed failures. Prominent among these in the United States was W. Kelley, of Eddyville, Kentucky, and your talented countryman, Mr. W. F. Durfee, addressed himself to the practical development of this invention; it was he who constructed the experimental steelworks at Wyandotte, Michigan. This was in 1862, the year of the great International Exhibition in London, where Holley had ample opportunity of studying the products of the Bessemer converter. We may be certain that what he saw there convinced him of the importance of the process for the United States. His judgment was confirmed by that of Zerah Colburn, who, with his usual foresight, had some time before become a strong advocate of the process. Writing in the London *Engineer* in 1862, Zerah Colburn said, "The fact that, as a substitute for wrought iron, at least where facility of welding is not of special consequence, the Bessemer metal is now known to be of established trustworthy character, is of itself a most important one, and as those who fully know the process are aware that ingots can be turned out by it at £6 a ton, and finished rails at less than £10, we have only to await the time when, through competition, this metal has been cheapened to an extent which will ensure its general application for the many purposes to which it is so admirably fitted."

When Holley returned to America early in 1864, having purchased the American patents, and learned the process, he and his associates found themselves confronted with the risks of costly litigation. It was claimed that the Kelley patents preceded and covered those of Bessemer, but after some delay this difficulty was removed by compromise. Indeed, on Mr. Durfee's own showing, the costly experiment to prove the value of the Kelley patents was really only a test of the Bessemer process. In an interesting paper read before your Society of Mechanical Engineers in 1884, Mr. Durfee says with perfect frankness, "I possessed myself of all the information attainable concerning the Bessemer process, and as it was confidently expected that Mr. Z. S. Durfee would be successful in his efforts to purchase the American patents issued to Bessemer for the various forms of apparatus for the production of steel by the pneumatic method, it was thought only to be anticipating the acquisition of property rights to use such parts of his invention as seemed suited for the purpose." The Wyandotte experiment developed no great results, but for it can be claimed the first production of Bessemer steel in the United States, and the first output of steel rails. After the return of Holley to America in 1864, the Troy Works were started, and the first charge of Bessemer metal was made on 16th February 1865. Let me refer you to Mr. R. W. Hunt's interesting paper on the original Bessemer steel plant at Troy, read before your Society of Mechanical Engineers in 1884. You will see from it that Troy was only a small works, with two 2-ton converters, but such capital steel was produced that enterprise and capital were convinced. During the month of May 1865, less than twelve weeks after the works were started, eighty charges were made, giving 118 tons of steel with 16·7 per cent. of loss; immediately after this the works were extended by the installation of a plant that included two 5-ton converters. Mr. Z. S. Durfee assumed the charge of the establishment, and Holley proceeded to construct steel-works in other parts of the country, commencing with those of the Pennsylvania Steel Company at Harrisburg.

The thorough efficiency of the Bessemer process having been thus demonstrated, there was no limit to the supply of capital required for the erection of steel-works, and Holley rapidly found himself almost unable to satisfy the demands made upon him for designing and starting new establishments. He, however, never knew what it was to have too much occupation, and the finest steel-works in your country bear evidence of his skill and industry; those of North Chicago and Joliet, the Edgar-Thomson Works at Pittsburgh, the Vulcan Works at St. Louis, the Cambria, the Bethlehem, the Scranton, and other works, were built under his instruction and from his plans. But more than this, Holley completely modified the details of the Bessemer process as he had learnt it in England; he adapted it to the special requirements of the American manufacturer, who was enabled, through the modifications he designed, to produce those stupendous outputs of steel, the records of which were so long received in England with incredulity. This is what the joint inventor of the basic process, Mr. Percy C. Gilchrist, wrote to me upon the subject of Holley's modifications and improvements:—

"101 Palace Chambers, Westminster, London,
July 14, 1890.

"I have the greatest admiration for the work Holley achieved, as I think that the present proud position of the American steel trade is very largely due to his genius. A lesser man would have copied the European steel-works, but instead of this, he picked out the weak places, and in the American works that were fortunately subject to his advice, one sees how their defects were avoided by him, how breakdowns were eliminated, labour saved, and output consequently increased.

"Holley from the very first appreciated the basic process, and was most kind and generous in his appreciation; he suggested at an early date that the more rapid wear of the basic lining of the converter should be met by removing the shell of the converter with its worn-out lining from its belt, and by replacing it with a fresh shell, ready lined; this plan was put into practice by Mr. Arthur Cooper at the North-Eastern Steel Company's Works at Middlesbrough, and is giving excellent results.

"I regret to say that I saw very little of Holley myself, but my cousin, the late Sidney Gilchrist Thomas, saw a good deal of him; they had much in common, both in ability, go-aheadness, and perseverance, and they had, I know, an intense admiration for each other.—Yours very truly,

"Percy C. Gilchrist."

One of your own engineers—Mr. R. W. Hunt—has summarised Holley's work in this direction. He says, "The result of his thought gave us the present accepted type of American Bessemer plant; he did away with the English deep pit, and raised the vessels so as to get working space under them on the ground-floor; he substituted top-supported hydraulic cranes for the more expensive counter-weighted English ones; he put three ingot cranes round the pit instead of two, and thereby obtained greater area of power; he changed the location of the vessel as related to the pit and melting-house; he modified the ladle crane and worked all the cranes and vessels from a single point; he substituted cupolas for reverberatory furnaces; and last, but by no means least, he introduced the intermediate or accumulating ladle, which is placed on scales, and thus ensures accuracy of operation by rendering possible the weighing of each charge of melted iron before pouring it into the converter. After building such a plant, he began to meet the difficulties of details in manufacture, among the most serious of which was the short duration of the vessel-bottoms, and the time required to cool off the vessels to a point at which it was possible for workmen to enter and make new bottoms. After many experiments, the result was the Holley vessel-bottom, which, either in its form as patented, or in a modification of it as now used in all American works, has rendered possible, as much as any other one thing, the present immense production." Vastly as all these modifications tended to increase the output, I think it is necessary to include one other factor that has helped to obtain such extraordinary results—the perfect organisation of the managing engineers and the remarkable efficiency of the American workmen. On this point a prominent English steel-maker wrote to me recently, after a visit he had paid to several of your leading works: "Of course the output was very large from each pit, and this was attained by great facilities for bringing up and getting away materials, and keeping everything at high pressure. The men, I dare say, are paid well, but it was hot weather when I was there, and they were certainly selling their lives."

But apart from organisation and skilled labour, the marvellous growth of production from Bessemer vessels in the United States must be credited to Holley. The fifteen years' development may be briefly summed up as follows:—In 1865, the output from two 2-ton converters in a month was 118 tons; in 1880, the output from two 5-ton converters was 14,000 tons. In 1866, the Pennsylvania Railway Company purchased from Messrs. John Brown & Co., 5000 tons of Bessemer rails at 120 dols. (gold) per ton; last year the production of Bessemer rails in the United States was about 1,644,000 tons. In the year 1868 the total output of Bessemer steel in America was 8500 tons; the same year in England it was 110,000 tons. In 1879 your production equalled ours, and from that date has always exceeded it, until the last year it reached the amazing figure of 3,169,643 tons, which was one million tons more than that of the United Kingdom. Since the first charge was blown at the Troy Works in 1865, there have been produced in America upwards of 25 millions of tons of Bessemer steel. And this is the record of the last eighteen years of Holley's life.

So the busy years passed, bringing with them a rich, if tardy, harvest of fame to Holley. He continued to be recognised as the one great authority in America on Bessemer steel; in Europe his reputation stood nearly, if not quite, as high. We all remember the prominent part he took in the Centennial Exhibition of 1876; his admirable reports on the iron and steel exhibits of that year, and which were followed by a long and masterly series of articles on the steel-works of the United States—a series which unfortunately remained unfinished. Some of us have had the privilege of studying his annual and confidential reports on the steel manufacture of the world. These reports are marvels of technical skill and labour; they attest also the unlimited confidence which he commanded, both at home and abroad, in the steel-works of Europe, as well as those of the United States. They were the result of periodical visits to England and the Continent, and were, during the last years of his life, prepared solely for the use of the Bessemer Association, with which he had entered into confidential relations. The gates of every steel-works in Europe were open to him, and from him no manufacturers' secrets were withheld. It was quite a unique position which he then occupied; one for which his long training, high intelligence, and perfect integrity absolutely fitted him. Manufacturers knew well that their secrets were safe in his hands; that if they gave him much, he brought still more to them; that his visits were always useful and suggestive, and that the exchange of American experiences for their own never left Holley their debtor. There was also another aspect to these annual visits. Time, hard work, and the cares of a busy life had never withered the great charm of Holley's character, but, on the contrary, his personal influence and indefinable power of attraction had increased with years. He was loved as much as he was admired; he was as popular in France, in Germany, and in Belgium as he was in England or the United States. Mr. Dredge then read the following letters:—

From Mr. James Riley, of the Steel Company of Scotland:—

"It was my privilege and pleasure to know Mr. Holley during several years, in the latter of which I think I may say that our acquaintance became as intimate as the circumstances of time and distance rendered possible. I think I am correct in stating that for the last ten years of his life he never came to Europe without visiting me, the last occasion being the one when he left us bravely struggling with the disease to which he finally succumbed.

"During these years of acquaintance of more or less intimate character, I had learnt to admire and esteem Mr. Holley; and the more I knew of him the greater was the regard, and, may I say, affection, I felt for him. One admired his great abilities, esteemed him for his frank, honest, manly nature; but more than this, one was drawn to the man by the grace and charm of manner and conduct which he possessed in such high degree. Feeling thus regarding Mr. Holley, I am glad to know that the Engineers of America have taken steps to perpetuate his memory, that we are invited to participate in this action on their part, and that you are to give expression to our admiration and esteem on the occasion of the inaugural ceremony.—Yours faithfully,

"JAMES RILEY."

Mr. E. Windsor Richards wrote as follows:—

"LOW MOOR IRON WORKS, NEAR BRADFORD, YORKSHIRE,
August 11, 1890.

"JAMES DREDGE, Esq.

"DEAR SIR,—I am very much pleased to learn that a statue is to be erected to the memory of our lamented friend, A. L. Holley, in Central Park, New York, and will be unveiled by you. It would be very gratifying to me to be present on that occasion, as I held him in the very highest esteem. It was sad that he should have gone from us when in the full ripeness of his career, when his abilities, sound common sense, and good qualities had become so well known to, and appreciated by, the leading metallurgists and engineers in the old country.

"Holley had a very difficult part to perform, one requiring great judgment and knowledge of men. Few succeed as he did. Manufacturers generally most jealously guard their trade matters. Holley disarmed them by being always as ready to communicate information as to receive it; he had always something of the highest interest in engineering and metallurgical matters to discuss.

"Nine years ago at this season he was directing the route for my visit to the States, a visit which afforded me so much pleasure and instruction, and which added many more names to my list of American friends.

"I am indeed glad that so many of his countrymen have joined to do honour to the memory of a man so eminent, so amiable, and so genial.—
Yours faithfully, E. WINDSOR RICHARDS."

Other letters were read from Messrs. Schneider et Cie., of Le Creusot; the Directorate of the Rheinische Stahlwerke, Ruhrort; the Directors of Witkowitz; M. Greiner of Seraing; and Mr. Arthur Cooper of Middlesbrough.

A passing reference should be made to the Thomas-Gilchrist process of making Bessemer steel, which was brought into prominent notice only three years before the close of Holley's career, at a time when his continued efforts had already broken down his magnificent constitution. The ill-fated Mr. Thomas in some respects resembled Holley, and they had sufficient subjects of interest in common to create a strong bond of sympathy between them. Always eager to know of what was new and of apparent value, Holley speedily made himself master of the basic process, and passed considerable time with the inventors at the works where the method was in operation. He quickly formed a high estimate of the value of the process, and made preliminary arrangements with Mr. Thomas for its introduction into the United States. Partly as a consequence of this arrangement, Thomas visited the States in 1879, and passed some weeks with Holley, inspecting the principal of your steelworks. It was on one of these occasions that Holley made the remark to Thomas, when he was fatigued and wanted to sit down, that "he must send over to England if he wished to find a cool ingot-mould." I think that Holley's early death was the sole reason why the Thomas-Gilchrist process is so little employed in the United States; the good opinion that Holley formed at the commencement has been fully justified by its large and successful adoption on the Continent of Europe.

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Did time permit, I should like to dwell at much greater length on the brilliant and successful years of Holley's career; the period of an abundant harvest, the seed of which had been sown with toil and judgment so many years before. But I must pass on to review very briefly some of the minor though important incidents that complete the picture of his busy life. The professional honours that were so fully his due fell thickly enough on him during the later years. He was elected President of your Institute of Mining Engineers in 1875; he was Vice-President of your Society of Civil Engineers in 1876; he founded your Society of Mechanical Engineers, of which Society you did me the high honour to elect me an honorary member; in 1877 he became a member of the Institution of Civil Engineers, a body which we in England are proud to regard as the parent of all the Anglo-Saxon engineering societies. Holley was also a member of the Iron and Steel Institute.

On the official positions occupied by him, the most important were as follows:—In 1875 he was appointed a member of the United States Board for testing structural materials; in 1879 he became lecturer on the metallurgy of iron and steel at Columbia College; and in 1878 he was given the degree of Doctor of Laws.

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Your faithful and enduring friendship has found graceful expression in marble and in bronze, in a statue which shall remain to speak to future generations of the great engineer who revolutionised the most important industries of America. But this memorial which you have erected is only the outward and visible sign of the spiritual memorial set within your hearts, to be kept there sacred through life, and beyond it. Many of you have seen carved over one of the portals of St. Paul's Cathedral the epitaph of its architect: "Si monumentum requiris, circumspice." So you must look around you for the monument of Holley. It stretches in a vast and ever-growing network over your country, from east to west, from north to south. Wherever railways are, his monument lies beneath you, as you travel over the lines of steel. You behold it in the vast piles of buildings devoted to the production and the manufacture of steel. The memorial to his great energy and intelligence is made visible in pillars of cloud by day, and in pillars of fire by night, in your greatest metallurgical centres. The development of your most important mineral resources; the contentment and prosperity that wait upon the vast army of labourers in the field where Holley first broke ground; the wealth that has attended those who were far-seeing and bold enough to support him; to no small extent, the marvellous growth of your great country, that causes us, the slow-moving nations of the Old World, to stand and gaze in wonder—all these great things together compose Holley's monument; so if you seek it, your gaze must not be restricted to narrow limits, such as those that bound the matchless pile reared by our great architect, more than two centuries ago; it must range from the Atlantic to the Pacific, from the Gulf of Mexico to the Arctic circle. On every piece of Bessemer steel that is converted to the service of the arts and industries in the United States might be engraved the words he used to write upon the many drawings he made in London during his first youthful visit, with such a rapid and unerring hand: "Holley Fecit."

I have completed the work your generosity has imposed upon me, and, with all its imperfections, this address must stand in the archives of your Societies, to bear testimony to my unfitness for the task. In one respect I feel a full measure of satisfaction; I have brought you from beyond the sea the proofs of how Holley was esteemed by strangers—a gift of precious pearls of human sympathy, worthy to be laid upon the base of your memorial column. Would that they were linked together by a golden cord, instead of being strung upon a thread of baser metal, sublimated from very common clay.

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PITTSBURGH MEETING.

PROCEEDINGS

OF THE

JOINT INTERNATIONAL MEETING

OF THE

IRON AND STEEL INSTITUTE,

THE

AMERICAN INSTITUTE OF MINING ENGINEERS,

AND THE

VEREIN DEUTSCHER EISENHÜTTENLEUTE.

HELD AT PITTSBURGH, October 9th and 10th, 1890.

THURSDAY, OCTOBER 9TH.

THE INTERNATIONAL MEETING of the three Societies was opened to-day in the Carnegie Hall, Allegheny City, Pittsburgh—Sir JAMES KITSON, Bart. (President of the Iron and Steel Institute), occupying the chair.

Mr. JOHN RICKETSON, Chairman of the Local Reception Committee for Pittsburgh and its neighbourhood, delivered the following address of welcome:—

Mr. President and gentlemen of the Iron and Steel Institute of Great Britain, of the Verein Deutscher Eisenhüttenleute, the American Institute of Mining Engineers, and of all kindred associations present here to-day—On behalf of our Reception Committee, representing as it does not only manufacturers of iron and steel, but our manufacturers, merchants, municipal authorities, commercial and industrial organisations, and citizens generally, I have the honour to extend to you, one and all, a most sincere and hearty welcome to the Pittsburgh district. While greeting most cordially all our guests, from whatever country they may come, we cannot refrain from tendering a special welcome to your distinguished President, Sir James Kitson, upon this his first visit to the United States; and to assure your past President, Sir Lowthian Bell, your Vice-Presidents, Mr. Windsor Richards, Mr. Martin, and Mr. Snelus, and your honoured member, Sir William T. Lewis, who have been here before, that it gives us great pleasure to see them again here. Many of us have met your accomplished Secretary, Mr. Jeans, in London, and remembering his many courtesies, warmly welcome him to our midst. Recalling also your magnificent hospitality to the American engineers who visited Europe last year, and especially the courtesy and kindness of your Institution of Civil Engineers, we would greet most cordially Mr. George Berkley, the senior Vice-President of that Society. It is a matter of deep regret to all your hosts throughout the length and breadth of the land, that one of your most distinguished members and past Presidents, Sir Henry Bessemer, was unable to accompany you. We heartily wish that his efforts to build a steamship to which sea-sickness was to be a stranger had been successful, and that he could have sailed, conquering and to conquer, across the Atlantic. Perhaps some of you, when in mid-ocean, wished so too. What could have been more in accordance with the fitness of things than at this time and place to have tendered the homage of our admiration and respect to the great man, the evidence of whose genius is to be seen in more than 160,000 miles of steel rails that to-day sparkle in the sunlight from New York to San Francisco, and from Montreal to the Gulf of Mexico. Among our German friends we are especially glad to have with us Dr. Wedding, Mr. Thielen, Mr. Daelan, and Mr. Schroedter. We regret the absence of the Hon. Abram S. Hewitt, the President of the Institute of Mining Engineers, the distinguished statesman, scholar, orator, and ironmaster, whom you have honoured with the Bessemer gold medal of 1890. We are, however, glad to see here some of the Vice-Presidents and members of the Council of the Institute, as well as its gifted Secretary, that "Admirable Crichton," Dr. R. W.

Raymond. We are glad also to announce this morning the official presence of the President of the American Iron and Steel Association—our highly-respected fellow-citizen, the Hon. B. F. Jones.

Mr. President, Pittsburgh numbers among its citizens one of the great inventors of our age, and I think you will agree with me that the two men, now living, to whom the world is most largely indebted for the safety of railway travel, are Sir Henry Bessemer, of Great Britain, and George Westinghouse, junr., of the United States. The one has given us the steel rail, the other the air-brake, both essential in heavy and rapid railway transportation.

I should be remiss in my duty did I fail also to regret the absence of our former fellow-citizen, a native of Great Britain, to whose generosity this city is indebted for the magnificent building in which we are now assembled—Mr. Andrew Carnegie.

[After paying a cordial tribute to Mr. Carnegie, and giving a brief outline of the geography of Pittsburgh and its vicinity, Mr. Ricketson continued]:—

We have here twenty-one blast furnaces, which in 1889 produced 1,293,435 tons of pig iron; thirty-three rolling-mills, twenty-seven of which roll steel, and their production in 1889 was 1,105,573 net tons of steel, and 638,450 tons of rolled iron. Our annual capacity of steel rails is at present 550,000 tons. Our product of wrought iron pipes this year will, I am informed, not fall short of 350,000 tons, while our output of structural iron and steel will be fully 165,000 tons. We have forty-nine iron founderies, representing a capital of nearly $10,000,000. The principal electrical industry in Pittsburgh is in apparatus for incandescent lighting. Of the dynamos in the United States, having a capacity for the supply of current for 1,500,000 sixteen candle-power lamps, Pittsburgh alone has furnished 650,000, or nearly 44 per cent. We have fifteen firms or companies making window glass, thirty-seven making flint and lime glass, and fifteen making green and black glass bottles. The 15,000 coke ovens in this district consume 9,000,000 tons of coal in making their product of about 6,000,000 tons of coke. In 1889, in round numbers, we shipped to Southern markets by river, 4,000,000; we shipped to Eastern markets by rail, 2,500,000; we shipped by rail for re-shipment by lake, 1,000,000; the railroads entering Pittsburgh used 1,000,000; we shipped by rail to North-Eastern markets, 500,000; we used for home and miscellaneous trade, 2,000,000; making a grand total of 20,000,000 tons, or about 60 per cent. of the output of bituminous coal in Pennsylvania.

The railway tonnage of Allegheny county, of business originating here, exclusive of what passes through, is 20,000,000 tons per annum, or a fraction over 3 per cent. of the total railway tonnage of the United States, which amounted in 1889 to 619,137,237 tons.

I am officially informed that in this district 750,000,000 feet of natural gas are delivered each day through 1125 miles of pipe to consumers in our mills and factories, and to upwards of 30,000 private warehouses, stores, hotels, and dwellings. The present annual displacement of coal by natural gas is estimated at about 8,000,000 of tons. There are 46,000 oil-wells in the United States, producing on an average 130,000 barrels per diem, and representing a capital of $120,000,000. There are 10,000 miles of pipe lines for the transportation of crude petroleum, involving a capital of $50,000,000. The stock in tanks at present of crude petroleum is 26,500,000 barrels. The country has a refining capacity of 140,000 barrels per day for illuminating oil; and 15,000 barrels per day are used for fuel purposes.

Gentlemen, when in addition to the 300,000,000 of barrels of petroleum which have flowed from the soil of Pennsylvania between 1876 and 1890, we remember that she is still producing 2,500,000 barrels per month; that her total yearly output of bituminous coal is 30,000,000 of tons, and of anthracite 35,400,000 of tons, and that she produced last year within a small fraction of one-half of all the pig iron, and more than half of all the rolled iron and steel made in the country, you can form some conception of the immeasurable and boundless, though then hidden, resources of the princely domain of 44,986 square miles which King Charles II. ceded to the Penns in satisfaction of a claim against the British Government for £16,000.

More than two thousand years ago, a Hebrew sage, in the spirit of prophecy, the fulfilment of which we are witnessing to-day, uttered these words, which in this presence seem like a benediction: "Every carpenter and work-master that laboureth night and day . . . the smith also sitting by the anvil and considering the iron-work; the vapour of the fire wasteth his flesh, and he fighteth with the heat of the furnace; the noise of the hammer and the anvil is ever in his ears, and his eyes look still upon the pattern of the thing that he maketh. He setteth his mind to finish his work, and watcheth to polish it perfectly. So doth the potter, sitting at his work and turning the wheel. . . . All these trust to their hands, and every one is wise in his work. . . . Without these cannot a city be inhabited. They shall not sit on the judge's seat, nor understand the sentence of judgment, and they shall not be found where parables are spoken. But they will maintain the state of the world, and all their desire is in the work of their craft."

Sir JAMES KITSON, Bart. (President of the Iron and Steel Institute), spoke as follows:—By the courtesy of the President and Council of the Institute of Mining Engineers of the United States, I have been invited to take the chair, and to open the proceedings of this Congress. It is a graceful compliment to those members of the Iron and Steel Institute who are your honoured guests at this moment—an acknowledgment of high consideration for scientific services rendered to a great industry by the Iron and Steel Institute, and a marked distinction conferred upon the President of that Institute. I gratefully accept the position, and I now undertake the duty because, although I am fully conscious of my own deficiencies, yet I feel that the Institute is worthy of the respect you show to it; and I know also that we have the happiness to count amongst our members men who merit the honours you offer, whose names are known throughout the world as metallurgists and leaders in scientific study of the laws which govern the acquisition and production of those metals which we know as iron and steel.

Our Institute is not exclusively British; in truth, it is cosmopolitan, having enrolled on its list of members distinguished metallurgists of the United States, Germany, France, Sweden, Belgium, Austria, Hungary, and Russia.

The birthplace and the head-quarters of the Institute are in England. It will therefore, I hope, not be considered in any way presumptuous if I ask you for one moment to consider how much the world is indebted to my native land for the vast benefits which mankind has received from its engineers and its manufacturers of iron and steel.

The inventions of Watt and Trevethick; the development of the steam-engine, with all its consequential powers; the construction of the locomotive, and the creation of the railroad by Stephenson, are directly the work of England and of Englishmen. These discoveries have made that system of railways and service of ocean-steamers which have brought the nations of the earth together, have made new lands accessible and of service to man, and are destined in due time to diffuse knowledge and civilisation into every quarter of this globe.

The puddling furnace of Cort, and his method of rolling the puddled blooms in grooved rolls, produced wrought iron in quantities and at a cost hitherto unattainable. Through these inventions South Wales became the seat of the rail trade, and it was enabled for many years to dominate and control the rail trade of the world.

The puddling furnace continued, from the latter part of the last to the middle of the present century, to be the instrument by which practically all the malleable iron in the world was made.

The hot-blast process of Neilson, patented in 1828, secured a great economy of fuel, and a large increase of production. It entirely changed the condition of the pig iron manufacture, and was truly ranked by Mushet as "a means of developing the national wealth, of equal value with Arkwright's invention of cotton-spinning."

The economy effected in the use of coal in the various processes of the manufacture of iron and steel, has been great and progressive.

The margin for economy which then existed has been narrowed. But still, you know, on the authority of Sir Lowthian Bell, the duty performed is by no means equivalent to the whole of the useful effect which coke is capable of affording. "Taking a ton as being able to produce 20 cwt. of pig iron from Cleveland ironstone, this, after an allowance for ash, &c., when burnt to carbon dioxide, represents 147·200 calories, whereas something like 90·000 calories has been the limit of the power obtained."

This sacrifice of 40 per cent. lends itself to reduction, as does the heat held in the stream of molten slag flowing from the furnace.

Nasmyth's steam-hammer gave the means of forging iron, which led to rapid developments and improvements in the applications of iron. The reversing rolling-mill engine of Ramsbottom has been invaluable in the rolling of plates and bars of great dimensions.

The forging-press, too, has been designed and improved by English inventors, to whom the world owes much for other mechanical appliances devised to meet the various wants of the Bessemer process, and the treatment of masses of iron and steel.

To you, probably the most important invention of modern times has been that of Sir Henry Bessemer. It has given you a material in quality and quantity for your railroads which it was a physical impossibility to obtain by the ancient methods of iron-making. It is no exaggeration to say that without the Bessemer process for steel rail-making, the present railway system in the United States would not now exist; and the settlement of the new lands you have peopled, and the binding together of the vast territory between the Atlantic and the Pacific under one civilised Power, would not yet have been effected.

Sir Henry Bessemer has been kind enough, at my request, to prepare, for communication to this meeting, an account of his discovery of the process for manufacturing what is known as Bessemer steel; and some history of his investigations, and the way in which, step by step, he overcame the difficulties he met with, and finally dispersed, in his developments of his remarkable invention.

The Siemens-Martin process for the manufacture of open-hearth steel met with its greatest development in England, and it has enabled us to produce a material suitable for the requirements of the shipbuilder, of which he has availed himself to a vast extent.

In Great Britain the production of Bessemer steel ingots in 1889 was 2,140,791 tons; of open-hearth steel ingots, 1,429,169 tons.

We in Great Britain and Ireland are justly proud of our mercantile marine.

The supremacy of our shipbuilders and of our shipping interest is based upon the excellent quality and the abundant supply, at a moderate price, of steel furnished by our steel-makers.

The demands of naval architects and marine engineers have been responded to with intelligence and enterprise. Plates, frames, shafts, forgings, steel castings of forms and dimensions thought impossible but a few years ago, have been manufactured at low prices. These productions have enabled our naval architects to design, and our builders to construct, the magnificent ships which are the pride of our navy and our mercantile marine.

The strength of our position, and the remarkable economy of this important industry, can be best demonstrated to you by a fact within my own personal experience. I have within the past two months, as chairman of a shipping company, entered into contracts for the purchase of several new first-class cargo-steamers, to be built of steel, of the most approved design, with triple expansion engines, at the cost of £7 per ton registered tonnage. These ships, of a carrying capacity of 4000 tons, will be built and afloat within five months from the laying of the keel.

This example will suggest to you that our methods must be economical, and that great attention is given to economy of management. For this we are much indebted to the researches of our chemists, not only in England, but also in Germany and France.

An interesting example of which is the use of basic slag as a manure.

This was first applied as a manure in England in the summer of 1885 by Professor Wrightson, of Downton, Salisbury, who was employed by the North-Eastern Steel Company to make a series of experiments. The results were so satisfactory that basic slag immediately became a marketable article instead of a waste product. Now in the twelve months ending June 1890, 103,680 tons were delivered from works in Great Britain. Owing to the very much more rapid development of the basic process in Germany, a very much larger quantity of slag has been produced; and during the past three or four years, not only has the whole make been utilised, but stocks have been used up, as well as a considerable proportion of the total quantity exported from England.*

The make of basic slag in Germany is estimated as about 325,000 tons for the year 1889.

The alloys of steel with other metals continue to be the subject of research and experiment. Many of our members have devoted earnest attention to this fruitful field of inquiry. Communications by Mr. Riley, Mr. Hadfield, M. Osmond, and others, will shortly come before the members, in papers or notes, in the Transactions of the Institute.

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* Mr. ARTHUR COOPER, of the North-Eastern Steel Works, Middlesbrough, has made the following communication on this subject:—

Basic slag, simply ground into a fine powder, was first applied to land in the country as a manure in the summer of 1885 by Professor Wrightson, of Downton, Salisbury, who was engaged by the North-Eastern Steel Company to make a series of experiments on our account. The results of these experiments, as well as the results obtained from its application in Germany, on a much larger scale, in the same year, were so satisfactory that basic slag immediately became a marketable article instead of a waste product. In the year 1886–87 the North-Eastern Steel Company built a mill for grinding the whole of their make (some 50,000 tons per annum). The table below shows the total amount of raw slag (unground) and ground (Thomas phosphate) delivered by the North-Eastern Steel Company during the last five years, as well as the amounts delivered by other steel-producing companies in Great Britain other than by the North-Eastern Steel Company over the same periods:—

	Raw Slag (Unground) delivered by the North-Eastern Steel Company.	Ground Slag (Thomas Phosphate) delivered by the North-Eastern Steel Company.	Total Slag, Unground and Ground, delivered by the North-Eastern Steel Company; Home and Export.	Total Slag, Unground and Ground, delivered by other Companies than the North-Eastern Steel Co.; Home and Export.	Total Slag delivered by all Works in Great Britain; Home and Export.
	Tons.	Tons.	Tons.	Tons.	Tons.
Six months ending June 1886	2,520	...	2,520	None.	2,520
Twelve months ending June 1887	47,294	...	47,294	None.	47,294
Twelve months ending June 1888	47,252	9,848	57,100	32,469	89,569
Twelve months ending June 1889	22,691	26,925	49,616	35,224	84,840
Twelve months ending June 1890	7,471	36,805	44,276	59,404	103,680

The greater portion of the raw (unground) slag has been exported from this country to the Continent. Germany, France, and Sweden have all taken large quantities. The

It may be stated, in general terms, that owing to the high cost of aluminium it cannot at present come into extensive use. Mr. Hadfield and M. Osmond agree that iron with silicon and iron with aluminium have many points of resemblance. But when the addition of ·15 of aluminium, the minimum amount that has been found efficacious, means an addition of 12s. 6d. to 20s. per ton on the cost of the steel ingot, its employment in

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table next given shows the steady growth of the home consumption, and the second one the export trade.

Home Consumption.

	Ground Slag or Phosphate Powder delivered by the North-Eastern Steel Company for Home Consumption.	Ground Slag or Phosphate Powder delivered by other Steelworks for Home Consumption.	Total Ground Slag or Phosphate Powder delivered by all Steel Works in Great Britain for Home Consumption.
	Tons.	Tons.	Tons.
Twelve months ending June 1886 . .	5,922	2,880	8,722
Twelve months ending June 1889 . .	8,525	5,200	13,725
Twelve months ending June 1890 . .	12,367	9,850	22,217

Exported.

	Ground Slag (or Phosphate Powder) and Raw Unground Slag exported by the N. E. Steel Co.		Ground Slag (or Phosphate Powder) and Unground Slag exported by other British Works.	Total Slag, Ground and Unground, exported by all British Steel Works.
	Ground.	Unground.	Ground and Unground.	
	Tons.	Tons.	Tons.	Tons
Twelve months ending June 1888 . .	5,057	46,121	29,669	89,569
Twelve months ending June 1889 . .	18,400	22,691	30,024	71,115
Twelve months ending June 1890 . .	24,437	7,472	49,554	81,463

From the above figures it will be seen that although, of the entire production, viz., 103,680 tons, only about one-fifth has been consumed in this country, yet the home trade is growing rapidly, now that the farmers are beginning to understand its manurial value.

competition with silicon, as "ferro-silicon" or "silicon spiegel" cannot be more than experimental.

The remarkable success which has rewarded the researches of inquirers and experimenters on the alloys of steel with chromium, tungsten, aluminium, and nickel, gives us good reason to stimulate our members to continue their exploration of this field. Amongst these alloys the most important results appear to have been obtained from the use of nickel as an alloy of steel.

It will be remembered that when Mr. James Riley's valuable communication on the subject of the alloys of nickel and steel was read before the Iron and Steel Institute meeting in May 1889, Mr. J. F. Hall, of Messrs. William Jessop & Sons, Sheffield, at once rose and laid claim to priority of invention, informing the Institute of the innumerable experiments he had been making with alloys of nickel and steel during several years past. Since then, continuous experimental research has been made into this matter. Under the superintendence of Mr. Hall, armour plates have been manufactured from this material, and tested by English Admiralty officials, giving results which run about 75 per cent. above any similar plates ever tested in England. During the

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With respect to the use of this slag in Germany as a manure, owing to the very much more rapid development of the basic process in that country, a very much larger quantity of slag has been produced; and during the past three or four years not only has the whole make been utilised, but stocks which had accumulated have been used up, as well as a considerable proportion of the total quantity exported from this country.

	Tons.
For the year 1886	200,000
„ „ 1887	250,000
„ „ 1888	275,000
„ „ 1889	325,000

The average composition of our ground slag is as follows:—

	Per cent.	
Lime	45·64	
Magnesia	5·92	
Alumina	1·50	
Peroxide of iron	2·10	=Metallic iron, 13·46 per cent.
Protoxide of iron	15·42	
Protoxide of manganese	3·40	
Protoxide of vanadium	1·35	
Silica	5·90	
Calcium	·40	
Sulphur	·32	
Phosphoric acid	18·10	

The degree of fineness to which it is ground is such that 85 per cent. of it will pass a sieve having 10,000 meshes to the square inch.

same period Messrs. Schneider & Co., of Le Creusot, France, have furnished nickel-steel armour plates which have been tested by the French, Danish, and Chilian Admiralty authorities, with results almost identical with those obtained by Mr. Hall. Within the last month a nickel-steel armour plate of Mr. Schneider's manufacture has been tested in the United States, and has given similar results. At the present time, Mr. Hall has under course of manufacture breech-loading ordnance cannon and projectiles for the English War Office, and he has already applied it in the production of rifle and sporting gun-barrels, boiler tubes for torpedo boats, telephone and telegraph wire. When it is considered that nickel-steel can be made in various tempers, giving tensile strain of 107 tons per square inch, with an elongation of 3 per cent. in 8 inches; 97 tons tensile, with an elongation of 7 per cent.; 50 tons tensile, with an elongation of 45 per cent., it is impossible to foresee to what uses this most remarkable material may not be put; and now that the various patents and interests owned by Mr. J. F. Hall of Sheffield, W. H. Marbeau of Paris, Wm. H. Schneider of Le Creusot, and Mr. James Riley of Glasgow, have been associated, their joint labours promise to give rapid development to this interesting alloy. Works have already been erected by this association in France, for the special manufacture of ferro-nickel, and will shortly be followed by others in England and in the United States of America.

The treatment of large masses of steel by tempering, hardening, and annealing in water, oil, or molten metal has been carefully studied, but the secrets of the behaviour of masses of steel in heating and cooling are yet far from being unfolded.

M. Osmond, in his excellent paper delivered before the International Congress in Paris last year, points out that tempering in oil was known to the ancients, being mentioned by Pliny; and Shakespeare also knew that the Moors had the knowledge that different temperatures of water effected the results of the hardening process. Othello says, "I have another weapon in this chamber; it is a sword of Spain, the ice-brook's temper." One day, in conversation with Mr. Gladstone, I related this to him. He at once capped the quotation by saying, "Yes, and I remember that Homer, in the 'Odyssey,' says: 'As when the smith dips into cold water the great axe or an adze, and it hisses

loudly as he is tempering it, for so it is that iron is made hard.' "
—(*Odyssey* ix. 391–394.)

I have ventured to make a passing mention of some of the men, and of some of the inventions, which were conceived and brought forth in our island home. I have named some of the inquiries and experimental researches which are being conducted by our metallurgists. You will see that we have need of many precious metals which your prolific country contains, to enlarge the properties of the materials demanded by our engineers, our army and navy, our ship and bridge builders. It is fortunate that we can make known these wants to men like the mining engineers of the United States, whose knowledge of those materials and their localities is as wide as their continent. We need these metals; we need also to feed and clothe our vast industrial population. For your grain and fruits, your cattle and cotton, your many remarkable mechanical devices, we have no precious metals to offer in return; but we have the products of our mines, the labour of our looms, the service of our mercantile marine. It is well that we should meet thus, eye to eye and voice to voice, to discuss the interests and the scientific aspects of the great industry which absorbs us. It is thus that we learn by persistent and intelligent labour how much has been accomplished, how much more remains to be achieved; and that by free exchange of ideas and of productions, friendly understanding is promoted and personal acquaintance is built up. Through such orderings we are convinced that Providence has designed to wind the silken chain of commerce round the world.

The following is the communication from Sir Henry Bessemer referred to in the address of the President, and handed by him to the American Institute of Mining Engineers:—

DENMARK HILL, *September* 10, 1890.

DEAR SIR JAMES KITSON,—It is with great pleasure that I accede to your request to furnish you with a brief outline of the circumstances which led to the invention of my steel process, the more so on account of the generous interest you have always taken in the invention, notwithstanding that it aims at the overthow of the older methods of producing malleable iron, in the production of which you have obtained so distinguished a position.

At the time of the Crimean War I had invented a mode of firing elongated projectiles from a smooth-bore gun, the rotation necessary to ensure their proper position during flight being obtained by utilising a portion of the powder-gas to produce rotation by reaction, after the manner of producing rotation in turbines, and not by the rifling of the gun, consequently rendering all smooth-bore guns at once suitable for firing elongated shot or shell. I of course offered this plan to our own Government, but it was discarded without a trial.

A little after this period I happened to be on a visit for a week or two, with Lord James Hay, at the house of his daughter in Paris. During this visit our host gave a farewell dinner to General Hamlin and several other distinguished officers in the French army, who were going out to the Crimea.

Among the guests on this occasion was Prince Napoleon, and while taking a cigar in the library after dinner, the conversation turned naturally enough on artillery, and I then mentioned my system of firing elongated projectiles from smooth-bore guns. The Prince was so impressed with the importance of this idea, that he said he was sure his cousin, the Emperor, would be much pleased if I would explain my invention to him, and that he would get an appointment made with the Emperor for this purpose. This was done, and I had a long and most interesting discussion with His Majesty, whom I found most thoroughly conversant with the whole subject of artillery.

His Majesty, in the kindest possible way, gave me *carte blanche* to make any experiments I desired at Vincennes.

A great many 30-pounder elongated projectiles were made, and were fired from a 4½-inch 12-pounder smooth-bore cast-iron gun at the Polygon at Vincennes. They were fired through a succession of thin wooden targets placed 100 metres apart, through all of which they cut circular holes, thus showing that they went end on: a thin coat of black japan had been purposely put on them, and when the shots were recovered from the bank in which they were lodged, the coat of japan was seen to be partially scraped off in spiral lines, caused by their passage through the wooden target; the angle of these scratches being carefully taken, showed that from 1½ to 2¼ rotations had taken place in the length of the gun.

After many hours' practice, on a cold December day, we retired to the officers' quarters in the old fortress of Vincennes, and while standing round a blazing wood-fire, sipping some hot spiced wine, Commandant Minie (the inventor of the rifle) observed that "although the rotation of the shot was effected, unless we had something better to make our guns of, such heavy elongated projectiles could not be used with safety."

This casual observation was the spark that has kindled one of the greatest industrial revolutions that the present century has to record, for during my solitary ride in a cab that night from Vincennes to Paris, I made up my mind to try what I could do to improve the quality of the iron used in the manufacture of guns.

My knowledge of iron metallurgy was at this time very limited, but this was in one sense a great advantage to me, for I had very little to unlearn, and so could let my imagination have full scope. After many months of trial, and much building up and pulling down of reverberatory furnaces, I cast a small model gun; the iron was very white, and in turning it, little short curly shavings were cut off. It was wonderfully tough for cast iron, but wonderfully brittle if classed as wrought iron. The little model gun looked very beautiful when highly polished, and I took it over to Paris and begged the Emperor to accept it, as the first-fruits of my studies of the metallurgy of iron. He expressed himself much pleased with it, and complimented me on having achieved a step in the right direction, and with his own hands placed it in a bureau, saying, "Some day it may become an interesting relic."

About this period I began to fully appreciate the fact that, if I could improve cast iron and render it malleable, and still retain its fluid state, apart from its use for artillery, it would be of the greatest commercial value for all engineering purposes. I therefore pursued my experiments with greater ardour than ever, for I was convinced that I was on the eve of producing a quality of metal that would supersede wrought iron.

At this time I devoted myself exclusively to these investigations, which were very costly, and I became most anxious to obtain the opinion of some able engineer as to the value of my invention, lest I might be deceiving myself, and living in a fool's paradise.

I consequently consulted Mr. George Rennie, the eminent civil engineer. I showed him a small upright fixed cylindrical converter, and in it we made a charge of 7 cwt. of Blaenavon pig iron into an ingot of malleable iron. Mr. Rennie was in raptures with the result, and said, "You must not keep this light under a bushel for a single day longer; and, by-the-bye, there is a first-rate opportunity for you. The British Association meet at Cheltenham next Tuesday: read a paper there, by all means. I am President of the Mechanical Section; it is true all the papers are arranged, but if you will write a paper, I will take the responsibility of putting it first on the list." He kept his promise, and I read my paper "On the Manufacture of Malleable Iron without Fuel," which appeared verbatim in next day's *Times*.

The entire iron trade of the kingdom was startled by the facts detailed in this paper, backed as they were by two small bars of malleable iron, one of which had been piled and re-rolled; a few days later the ironmasters came trooping up to London to see the new process. There are many interesting incidents connected with these visits, which I cannot trespass on your time to relate; but some idea of the excitement may be gathered from the fact that, notwithstanding the imperfect state of the process at that time, I was actually paid £27,000 for licenses granted within one month of the reading of my paper. At many ironworks the managers set to work to test the invention in the rudest possible manner, with such means as they had at their disposal, all of which attempts were failures. In my experiments I had used Blaenavon pig iron, which was successful; and at that time I had no idea that other brands of iron would fail in the manner they did. No sooner were these failures known than an extraordinary revulsion of feeling was manifested, and the most perfect distrust of the invention became universal. The public press, which had spoken of it in such glowing terms, now condemned it as impracticable, and spoke of it as "a brilliant meteor that had flitted across the metallurgical horizon, dazzling a few enthusiasts, and had then vanished for ever in total darkness."

Prior to this invention, pure malleable iron in a fluid state was wholly unknown; indeed, whole days of exposure to the most powerful furnaces then in use entirely failed to bring this material into a state of fusion, notwithstanding which I proposed to convert ordinary melted cast iron into this malleable fluid state, in quantities of five tons at a single operation, and in the short space of fifteen minutes, by the mere chemical action of cold atmospheric air, and in the entire absence of any fuel whatever, except that which existed in the form of carbon and silicon in the crude metal itself. It is not surprising, therefore, that the ironmasters, as well as the whole press, joined in one general chorus of condemnation of what they then believed to be a perfect chimera, which none but a wild enthusiast could ever have believed to be possible. I knew far otherwise, but this was no time to argue the question. Words would have been of no avail, so I set earnestly to work to try and master the difficulty that had so unexpectedly arisen. This was no easy task.

All the old investigations had to be gone over again; experiments on a much larger scale, with larger and more powerful machinery, were found necessary; but the difficulties to be surmounted had reference more to chemical than mechanical questions: a laboratory was therefore fitted up, and I engaged the services of a professor of chemistry, at a high salary, to make analysis of all the iron and other materials employed in our experiments, as well as a systematic analyses and classification of all the results obtained. The very large scale on which these operations were carried out involved a considerable outlay in various ways, but there was no slackening of exertion, no cessation of severe mental and bodily labour: in this way another long and weary year had passed, and but little real progress had been made towards the removal of the difficulty. Many new paths had been struck out, but they had led to no practical results. Several weeks were sometimes necessary to make and fit up the apparatus required to test each new theory as it was formulated, and it too often happened that the first hour's trial of the new scheme dashed all the high expectations that had been formed, and we had again to retrace our steps. Thus week after week went on amid a constant succession of newly-formed hopes and crushing defeats, varied with occasional evidences of improvement. I, however, worked steadily on. Six months more of anxious toil had glided away, and things were much in the same state, except that many thousands of pounds had been uselessly expended, and I was much worn by hard work and mental anxiety. The large fortune that was almost within my grasp now seemed far off; my name as an engineer and inventor had suffered much by the defeat of my plans. Those who had most feared the change with which my invention had threatened their long-vested interests felt perfectly reassured, and could now safely sneer at my unavailing efforts; and, what was far worse, my best friends tried, first by gentle hints, and then by stronger arguments, to make me desist from a pursuit that all the world had proclaimed to be utterly impossible. It was, indeed, a hard struggle; I had well-nigh learned to distrust myself, and was fain at times to surrender my own convictions to the mere opinion of others. Those most near and dear to me grieved over my obstinate persistence—but what else could I do? I had the most irrefragable evidence of the absolute truth and soundness of the principle on which my invention was based; and with this knowledge I could not persuade myself to fling away the promise of wealth and fame, and lose entirely the results of years of labour and mental anxiety, and at the same time confess myself beaten and defeated. Happily for me the end was nigh, and in a few more months I had fully succeeded in producing steel worth £50 to £60 per ton from charcoal pig iron which had cost me only £7 per ton, the conversion of the crude iron into steel being effected by simply forcing minute streams of cold atmospheric air upwards through it for a space of fifteen minutes.

Thus was the so-called fallacious dream of the enthusiast realised to its fullest extent, and it was now my turn to triumph over those who had so confidently predicted my failure. I could now see in my mind's eye at a glance the great iron industry of the world crumbling away under the irresistible force of the facts so recently elicited. In that one result the sentence had gone forth, and not all the talent accumulated during the last 150 years, of all the thousands whose ingenuity and skill had helped to build up the mighty fabric of the British iron trade—no, nor the millions that had been invested in carrying out the existing system of manufacture, with all its accompanying powerful resistance, could reverse that one great fact, or stop the current that was destined to sweep away the old system of manufacturing wrought iron, and establishing homogeneous steel as the material to be in future employed in the construction of our ships and our guns, our viaducts and our bridges, our railroads and our locomotive engines, and the thousand and one things for which iron had hitherto been employed; and yet, with all this newly-developed power, I was paralysed for the moment in face of the stolid incredulity of all practical iron and steel manufacturers, which stood like the solid wall of a fortress, barring my way to the victory I had already won. I announced the fact of my complete success to the world, and held in my hands the most undeniable proofs of the truth of my assertion, but no one would now believe it possible. They remembered but too well the great expectations that were excited two years previously by the first announcement of my invention at Cheltenham, and were not again to be disturbed by the cry of "Wolf!" Thus it happened that, after the hard battle I had fought for so many years, I found myself as far as ever from the fruits of my labour, for not a single ironmaster or steel manufacturer in Great Britain could be induced to adopt the process.

Anxious to possess still further practical proofs of the value of my invention, I made a few hundredweight of steel bars, at my experimental works in St. Pancras, of all the sizes and special qualities required in an engineer's workshop. These I took to the works of my friends, the Messrs. Galloway, engineers, of Manchester; and, unknown to any of their workpeople, these bars were given out and employed for all the purposes for which steel had hitherto been used in their extensive business. So identical in all its essential qualities was this steel with that usually employed by their workmen, that during two months' trial of it not the slightest idea or suspicion that they were using steel made by a new process was ever entertained by them—in fact, they were accustomed to use steel of the best quality, costing £60 per ton, and they had no doubt whatever but that they were still doing so.

I may here remark that this tool-steel was made from Swedish charcoal pig iron, costing, delivered at Sheffield, £7 per ton, and it was with this high-class raw material that our firm continued, for about two years, to manufacture tool-steel for engineers, for which we obtained £44 per ton, and for which such firms as those of Sir William Fairbairn, Sir Joseph Whitworth, and Messrs. Sharp, Stewart & Co., were regularly supplied up to the time when larger and more profitable work had made it not worth our while to continue the manufacture of tool-steel. Indeed, so satisfied were Messrs. William and John Galloway with the crucial test of our tool-steel at their works, that they entered into partnership as steel manufacturers with myself, my partner, Mr. Robert Longsdon, and my brother-in-law, Mr. Allen.

We built a steel-works in the town of Sheffield, determined to beard the lion in his den, and to undersell the trade until we forced them in self-defence to take a license under my patents and carry on my process. We at once got to work, and dropped £10 per ton on railway tyres, &c. This soon brought the trade to a proper frame of mind. Sir John Brown & Co. applied for a license; this was soon followed by Messrs. Charles Cammell & Co., and licenses were also granted to many other firms. Of course, we thus created a strong rivalry with our own firm, and forced our own prices down; this we were fully prepared for, as it still left a very large margin of profit.

Some idea may be formed of its importance as a manufacture when I state the simple fact that, on the expiration of the fourteen years' term of partnership of our Sheffield firm, the works, which had been greatly increased from time to time entirely out of revenue, were sold by private contract for exactly twenty-four times the amount of the whole subscribed capital of the firm, notwithstanding that we had divided in profits during the partnership a sum equal to fifty-seven times the gross capital; so that, by the mere commercial working of the process, apart from the patent, each of the five partners retired, after fourteen years, from the Sheffield works, with eighty-one times the amount of his subscribed capital, or an average of nearly cent. per cent. every two months—a result probably unprecedented in the annals of commerce.—Yours faithfully, HENRY BESSEMER.

The following paper was then read:—

ON THE PROBABLE FUTURE OF THE MANUFACTURE OF IRON.

BY SIR **LOWTHIAN BELL**, BART., F.R.S. (Past-President).

WITH the exception of air and water, it is open to question whether there is any form of matter which the human race could less easily spare than iron. Short of going the length of asserting that, without this metal for an anchor, or steel for the compass, the adventurous navigator could never have crossed the wide Atlantic, we may credit the locomotive and the steamer, and hence iron, with that sequence of events which has peopled North America with the Anglo-Saxon race. The result has been to raise a vast territory to a position without a parallel in the progress of the world.

To the attractions afforded by this interesting episode from modern history may be added the unprecedented development, in the United States, of that branch of industry which most concerns this Society.

Let me here remind you, although we are guests upon the present occasion, and Great Britain is the birthplace and home of the Iron and Steel Institute, its name and constitution were intentionally adopted so as to exclude geographical boundaries from being any limit to the scope of its operations. Accordingly, these cosmopolitan intentions have been followed by our numbering in our ranks considerably above 200 members belonging to other countries, and of these, nearly one-half are inhabitants of the United States. This union between members of one great family is a subject of sincere congratulation to the founders of the body, and, I feel sure, is not without interest to those who have joined it from the continent of Europe.

The present assembly is, so far as my reading goes, without a precedent in the annals of industry. Manufacturers of a metal from the Old World, where, in spite of what has been said by some antiquarians to the contrary, iron probably has been made for thousands of years, have accepted a courteous invitation from those of the New, with a view to discuss questions of interest common to both. To carry out this intention, three representatives from each hemisphere have been deputed to prepare subjects for this international congress, and I shall always consider my having been chosen by the Council of the Institute, to act on their behalf, as a very high and flattering distinction.

The heading of this paper implies that I propose addressing myself to the future rather than to the past, but as any estimate of the probability of what is going to happen must be founded, to a great extent, on what has already taken place, some reference to the ancient history of the iron trade would seem not altogether superfluous.

As is well known, man, in the earliest days of his existence, is supposed to have supplied his wants, first with implements of stone, and then of bronze. This conclusion had been arrived at by the discovery of articles suitable for the chase, for war, and other purposes, made of one or other of these two substances, whereas iron was never met with, and hence prehistoric man was regarded as having known little or nothing of the existence of this metal. More recent explorations, however, have proved that instruments of iron, when protected from atmospheric influence, had frequently been employed in different parts of the world. If, then, as is quite possible, implements made of stone or of bronze were in use long before those of iron, it is perhaps equally certain, that the latter metal was more commonly known at a very remote period than was, at one time, believed.

Apart from these discoveries, let us consider the question of a knowledge, by the ancients, of the existence of iron as one of mere probability. The ores of this metal are by far the most abundant of all metalliferous minerals, and they are met with in almost every geological age. In the lowest type of savage life, it could scarcely have escaped notice that a morsel of this abundant ore, if surrounded by glowing charcoal, produced a metallic mass, capable of being forged into objects greatly prized in daily life. Captain, now Colonel, Grant, the companion of Speke, found the isolated barbarians, near the great African lakes, familiar with this mode of obtaining iron; and he made a sketch for me, showing a couple of men engaged in this occupation. The means employed was simply a Catalan fire, of a less rude character than others which have been described by different authors. Some of these depended on the wind for their blast, whereas each man in my drawing is seen manipulating a couple of single-action bellows.

As regards steel, we know that in comparatively remote antiquity, the low Catalan fire had its dimensions so increased that white cast iron could not have failed to have been formed, and with this at hand, the power of producing the less carburised form of the metal could scarcely have long remained a secret.

So much for speculation; but we have more recently obtained proof that the ancients appear to have had far more knowledge of the metallurgy of iron than that for which they have received credit. How else can we account for the forging of a column of the welded metal, nearly 25 feet high, and weighing some 6 tons? It is of great, but unknown, antiquity, and was found standing upright at Delhi, where it still remains. Heavy masses of iron have also been discovered for supporting the masonry in doorways and other openings in ancient buildings; and although the blast furnace appears not to have been known when Agricola wrote his *De Re Metallica*, dated 1556, evidence is not wanting that carburised or cast iron has been found dating from a much earlier period. These admissions, of course, do not necessarily imply any knowledge of the property of iron to unite with carbon, and form a body capable of cutting iron itself, and of chiselling the hardest rock. The absence of this equally corrodible compound from the monuments of antiquity is, however, less difficult to account for than that of any other metallic bodies, all of which are less liable to perish from the action of the atmosphere than steel.

Coming down to a more enlightened period, the precise date of the invention of the blast furnace, the *haut-fourneau* of the French, and *Hoh-ofen* of the Germans, is still not known, but it is supposed to have been introduced at the latter part of the sixteenth century. The first change effected by the discovery was the gradual and almost complete banishment of the Catalan ore process, but while pig iron became the source of malleable iron, the Catalan, or a similar form of furnace, was retained for the purpose of conversion, and it remained in use for 200 years or more. Its place was gradually taken by the puddling furnace of Cort, which, with the exception of the small quantities of expensive bar iron made in Russia and Sweden, served to produce almost all the metal required in the malleable form since its invention in 1784 down to the year 1860.

When I was invited to undertake my present duty, without having any very definite plan in my mind, it occurred to me that the selection of some question in which coming events had been disregarded by iron manufacturers might not be an unprofitable use to make of the opportunity placed at my disposal. The particular event which first suggested this choice took place so recently as twenty-five years ago. The process of puddling, of course, is a very familiar one to every one in this room. It consists, as we all know, in melting pig iron in a furnace on the reverberatory principle, after which the workman, by very severe and exhausting labour, stirs the fluid metal, and thereby constantly exposes fresh surfaces to the oxidising influences present. This treatment burns off the greater portion of the associated metalloids, viz., carbon, silicon, sulphur, and phosphorus, which the metal has absorbed during its passage through the blast furnace. So severe is this labour that two men have their strength a good deal taxed in producing, for a day's work, 22 cwts. of puddled bars. To obtain this, an equal weight of coal has to be thrown into, and consumed on the grate of, their furnace.

Something like thirty years ago, Henry Bessemer proposed a plan in which the strong and never-tiring arm of the steam-engine should do the work of the wearied puddlers, and the heat required was supplied, not by coal, but by the combustion of the metalloids just referred to. Instead of 22 cwts. being the weight, and 12 hours the time, 10 or 12 tons of cast iron, in very little more than the same number of minutes, are rendered malleable, the duty of the men, during the conversion, consisting chiefly in watching the progress of the operation.

In viewing the impressive but simple process of "blowing" a charge of metal, it is difficult to realise the disappointments and the large expenditure of money and indefatigable energy required before the position referred to was reached. As a matter of history, however, in the year 1870, such substantial progress had been made, that 240,000 tons of Bessemer ingots were delivered for consumption. But what had been the action of the puddling-furnace owners during the onward march of this formidable and threatening competitor? It was this—in the year 1860, the number of puddling furnaces at work in Great Britain was given at 3462. In 1870 they had increased to 6700, which grew to 7575 by the end of the next five years. In 1887 the number, on the other hand, had fallen to 2875, in which year it was estimated that, in the North of England alone, there were 1000 puddling furnaces unemployed, representing, including the finishing-mills, 1½ million sterling. In Wales 600, and in the remainder of the United Kingdom another 1000, had shared a similar fate. Thus there was in 1887 property which must originally have cost nearly four millions sterling lying idle. In addition to this calamitous change, the 2875 furnaces at work were not actively engaged above three-fourths of their time. In the meanwhile, the manufacture of Bessemer steel went on increasing, so that in 1879 there was produced in the United Kingdom above one million tons, and above an equal weight in other countries. Since 1887 the number of puddling furnaces in operation has risen to 3346 in 1889, but the annual production of Bessemer and open-hearth steel has increased from 1,000,000 to 3,569,960 tons. It cannot, however, be questioned that the iron manufacturers were placed in a position of extreme uncertainty and difficulty. The superiority of steel, particularly as a material for rails, had been amply proved, but it had also been thoroughly ascertained that the hæmatites of Cumberland and Lancashire were the only ores in Great Britain suitable for Bessemer purposes. The growing demand for steel, therefore, soon exceeded the powers of supply from these two counties, and the consequence was a rise in the price of their pig iron far exceeding that of districts the produce of which was useless for steel-making. The market values of Cleveland and West Coast of England metal are here given to show the nature of the differences which arose after the change of conditions referred to, the quantities being stated in thousands of tons:—

Year.	1870.	1871.	1872.	1873.	1874.	1875.	1876.	1880.	1882.	1884.
Pig iron . . .	5,963	6,627	6,741	6,566	5,991	6,365	6,555	7,749	8,586	7,811
Cleveland, price	50/3	49/8	97/1	109/2	70/11	54/6	37/4	45/	43/5	37/
West Coast, price	72/3	89/6	170/	156/9	108/6	78/3	59/4	81/6	56/7	44/11
Difference of price	22/	39/10	72/11	47/7	37/7	23/9	22/	36/6	13/2	7/11
Imported ore . .	208	211	576	738	1,009	738	972	3,060	3,692	3,135

The embarrassment experienced at this time was further intensified by an almost unprecedented activity in the general iron trade of the country, which, finding no relief from Cumberland or Lancashire, had to be met by the metal obtained from the more plentiful ores of Cleveland and Lincolnshire, &c. As usually happens upon such occasions, the excited state of the market in Great Britain affected prices in the world at large, so that a state of things similar to that described prevailed in every part of the civilised globe, where iron was largely made.

Gradually the existence of a deposit of hæmatite ore in the North of Spain seems, so far as its abundance and ease of extraction were concerned, then to have dawned, for the first time, on the minds of the British ironmasters. Improvements in the navigation of the river Nervion, and in steam navigation, have enabled the produce of the mines at Bilbao, not only to compete, in point of price and quality of metal, with that on the west coast of England, but also with the cheaply wrought and most favourably situated bed of ironstone spread over a great tract of country in the hills of Cleveland. Gradually the large rail trade of Middlesbrough was extinguished, and, to a large extent, its manufacture of iron boiler and ship plates has suffered in like manner. As a result of this revolution, something like 48 out of 103 furnaces in the North-Eastern district of England, all erected for smelting native ironstone, are now engaged in providing pig iron from imported ores for the steelmakers. Nor has the disturbance in question been confined to this locality, or to other cheap iron-making centres, but the hæmatite mines of Cumberland and Lancashire have also been seriously affected by having to compete with these foreign ores. This may be judged of by the fact that, while twenty years ago the importations were only 130,000 tons, they amounted last year to 4,031,265 tons.

While considering whether a useful lesson might not be learnt from this retrospect of our trade, particularly by members of our Institute of less advanced years, reports reached me from opposite quarters of the globe of the so-called "direct process," beginning again to occupy attention. A favourable opinion has been expressed by some authorities well qualified to judge of a scheme which, if successful, might become a rival to the united power of the blast furnace and the Bessemer converter.

The great advantages possessed by the present mode of treating the ores of iron are too well understood to render it necessary that the blast furnace should occupy our attention at any length upon the present occasion. These, therefore, will only be spoken of in order to contrast them with those of a system by which it is intended to obtain wrought iron and steel by the direct treatment. In doing this, it will be made apparent that the blast furnace is able to perform a duty which has never been approached by any other form of apparatus, viz., the complete reduction of the metal contained in the ore.

Many eminent metallurgists have regarded with favour the principle contained in a variety of the processes known as "Direct," and it must be admitted that there is, in the idea, a simplicity, as compared with the present mode of manipulation, which is highly attractive. In the latter, the iron from the blast furnace has been made to unite with certain metalloids, we knowing at the same time that, in order to render the product malleable, these substances have to be removed. Among those who have laboured in this field, not the least distinguished was my late friend, a former President of this Institute, Sir William Siemens. In the hope of solving a problem in which his predecessors had not been successful, he spared neither time nor money. Ritter von Tunner, a high authority in all things connected with iron, has, in our frequent correspondence on such matters, extending over many years, expressed himself at one time hopefully on the direct process. In a recent communication, however, he seems to have abandoned all expectation of its being able to compete with the combined forces of the blast furnace and the Bessemer process. On the other hand, so far as I know, Siemens died believing in its future success.

I have elsewhere endeavoured to prove that reduction is not exclusively effected in the so-called reducing zone of the blast furnace; on the contrary, that oxygen, amounting to about 25 per cent. of its original quantity, arrives at or near the tuyeres, combined with iron in the form of some suboxide. Further, that final deoxidation of this suboxide is probably effected by a quantity of carbon, generated by a dissociation of carbonic oxide, as expressed by the formula, $2CO = C + CO_2$. This reaction is inferred from the result of numerous experiments in the laboratory, and from repeated observation at the furnace itself, confirmed by the fact that the gases at the tuyeres contain a quantity of oxygen, about 2 cwts. per ton of metal produced, and something like 1½ cwts. of carbon; the former not being accounted for by the atmospheric air used, nor the latter by the weight of fuel burnt in the hearth. Whether it is the actual carbon precipitated from the carbonic oxide, or coke itself, which completes reduction, or not, in a heat-producing point of view, is immaterial; what seems proved is, that it is reserved for the crucible to complete this work at or about the period when fusion takes place.

As a theoretical proposition, we have been reminded that the exact quantity of carbon required to deoxidise 20 cwts. of iron, in the form of ferric oxide, is 4·38 cwts. It is further assumed that this mixture of ore and carbon must be raised to a temperature of 800° C., for which, provided the entire carbon used is burnt, half to monoxide and half to dioxide, 1·27 cwts. ought to suffice. It is suggested, not that the work can be done for these 5·65 cwts., but that they are the limits towards which we may work.

We will imagine, as indeed has been proposed, that the operation is carried out in the furnace used by Siemens, which was one of the reverberatory type, constructed on the rotating principle. As bearing immediately on this question, it may be mentioned that, after a vast number of experiments, I arrived at the conclusion that the following temperatures may be regarded as those which are required for setting up the actions given in the subjoined table:—

		C.	F.
CO .	carbon-monoxide commences to reduce calcined Cleveland ore at	210°	410°
C .	carbon commences to reduce calcined Cleveland ore at* . .	399°	750°
CO_2 .	carbon-dioxide commences to oxidise spongy iron . . .	426°	800°
„ .	„ expelled from limestone	538°	1000°
„ .	„ commences to dissolve Carbon	815°	1500°

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* Cleveland ore is specified, because there are slight variations in the temperatures at which different ores are affected by CO.

It must be understood, however, that, at the temperatures named, the action goes on but slowly, although it speedily increases as the heat is raised.

Returning for a moment to the blast furnace, we have in the crucible, the zone of greatest heat, fusion of the slag and iron, and removal of the last portions of oxygen from the iron.

During the next 40 feet in height the chemical changes are insignificant, that portion of the interior being almost entirely utilised by the descending materials absorbing the heat contained in the gases, and returning it to the hearth.

At a distance of 60 feet from the hearth the carbon dioxide is given off from the limestone, where the temperature, as a rule, suffices for this gas to dissolve carbon, and thus prevents its combustion at the tuyeres.

Lastly, reduction in the upper zone is effected, where the temperature in a modern furnace ought never to be such as, with good coke, would permit the resulting gas acting on carbon ($CO_2 + C = 2CO$).

So far as my observations, experimental and otherwise, have enabled me to judge, the maximum quantity of oxygen representing the second equivalent in carbon dioxide in the gases, is that corresponding with the equivalent contained in the ferric oxide of the ore. From this it might be inferred that reduction is completed in what has been generally known as the reducing zone, *i.e.*, the uppermost and cooler portions of the furnace. We know, however, that the deposition of carbon, accompanied by the generation of some carbon dioxide, as already mentioned, is also most abundant at moderate temperatures. These facts might reasonably lead us to expect a quantity of carbon dioxide in excess of that due to the reduction of ferric oxide by carbon monoxide.

It will, however, be shown immediately that a condition of equilibrium in the gases is determined, not alone by the relative quantities of the two carbon oxides, but also by the amount of oxygen still remaining in combination with iron. Now, bearing in mind that the quantity of carbon required to be burnt at the tuyeres, in order to fuse the slag and iron, added to that rendered necessary to reduce the metalloids found in the pig, is such that at the various temperatures through which the ore descends, a position of equilibrium is reached, when the gases contain at the outside about 6 cwts. of carbon per ton of iron in the form of dioxide, and when the metal still retains about one-fourth of its original quantity of oxygen.

This observation refers to ores of the type of Cleveland, but with those of a different character the composition of the gases may be materially modified. Thus, in certain Swedish furnaces, the fuel consumed does not greatly exceed two-thirds of the quantity necessary for smelting the Cleveland ironstone. The volume of carbon monoxide for every ton of iron is correspondingly diminished, the result being that, instead of having two volumes of this substance in the escaping gases for each volume of carbon dioxide, the two gases are found in almost equal volumes. In one respect, however, all furnaces agree, viz., in there being an increase of carbon and oxygen in the gases at the tuyeres, as compared with that found a short distance above this level.

Thus it will be seen that at no time during the descent of the ore in a properly constituted blast furnace is it, with one exception, ever exposed to a high temperature, in an atmosphere of gases capable of oxidising iron. The exception is when carbon monoxide is split up into carbon and carbon dioxide; and then the precipitated carbon serves, as has already been observed, to remove the oxygen taken up by the iron during the dissociation of the carbon monoxide, when the ore arrives at the tuyeres.

Now, it is not too much to say that the conditions of every reverberatory furnace are the very reverse of those just laid down. If coal is the fuel burnt, which generally is the case, we have, passing over the materials, vapour of water, carbon dioxide, and very often a good deal of free atmospheric air, heated probably at least to 1500° C.* Thus exposed, spongy iron, when formed by direct reduction, as proposed, could not fail to be very rapidly oxidised. But the circumstances under which it is now expected to produce spongy iron consist in burning half the carbon to dioxide, and the other half to monoxide. From the information contained in the table just given, we learn that while carbon monoxide is a reducing agent, the product of reduction—carbon dioxide—is of an opposite character, and, in consequence, is able to reoxidise the metallic iron by the production of which it was generated. The cause which determines this reflex action is difference of temperature, and, as might be expected, when both gases are present there is brought about a position of equilibrium, determined, as has been said, not by temperature alone, but also by the extent of the oxygen still remaining united with the iron.

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* Of course it would be quite possible to maintain an excess of the reducing gas—carbon monoxide—in the furnace, but this merely means a great waste of fuel.

Thus, if a mixture of 2 volumes of carbon monoxide and 1 volume of carbon dioxide is passed over calcined Cleveland ore at about 417° C., one-third only of the oxygen can be removed, *i.e.*, the ferric is reduced to ferrous oxide.

If, on the other hand, the gas consists of equal volumes of the oxidising and reducing gases, the same effect is produced, provided the temperature is raised to a bright red; and spongy iron similarly exposed is oxidised, and becomes also ferrous oxide.

At a white heat the attraction of the metal for oxygen is so intensified that further action ceases when 12 per cent. of the combined oxygen is removed from the ore. At the same time 10 volumes of carbon dioxide are able to keep in check the reducing power of 90 volumes of carbon monoxide.

I see no reason, however, why a close approximation to complete reduction, in the direct process, should not be effected by using a sufficient quantity of carbon mixed with the ore, in the manner already described. The difficulty to be apprehended is the re-oxidation of the spongy iron when, by the revolution of the furnace, a fresh surface is exposed to the flame which is serving to heat the materials under treatment. Certain it is that Siemens failed to reduce the loss of metal to within reasonable limits. Forty-five years ago I laboured for some time with Mr. William Neale Clay, who was very sanguine of being able to dispense, wholly or partially, with the blast furnace. The results, in our case, were the same as those obtained by others who have followed us in the same path since that time. As regards the carbon, required as a source of heat, for raising the temperature of the mixture of ore and carbon, I see no prospect of reducing this with any approach to the quantity previously named, *i.e.*, 1·27 cwts. per ton of iron. Not only theoretically, but practically, in the Bessemer converter, the combustion of the metalloids and a portion of iron suffices to raise the bath of melted cast iron to a proper temperature, for keeping malleable iron in a state of fusion. Attempt the same thing in a puddling furnace, rotating or otherwise, and the oxidation of the same metalloids and iron, producing the same quantity of heat as in the converter, requires to be supplemented by the heat afforded by 15 cwts. of coal, in each case commencing with iron in a fluid state. In both, there is a great loss of heat at the chimney, but this we will neglect, and regard the remainder in each as due to radiation, convection, &c., inseparable from the larger size of the furnace, and the small amount of work turned out as compared with Bessemer's apparatus.

If, however, we take the weight of a cubic foot of pig iron, and contrast it with the same volume of the mixture to be employed in the direct process we are describing, the iron turned out, on such a mode of computation, will be about one-tenth of that obtained when pig iron is the raw material. To what extent the 15 cwts. of heating coal per ton of iron will be increased, by any such diminution in the yield of product, it would be difficult to predict, but it is perhaps not necessary to pursue this branch of the enquiry at greater length in this place.

Up to this point, the economy of the direct process has been argued upon thermal and chemical grounds, but the question of the capabilities of a reverberatory furnace, as compared with the united action of a blast furnace and a Bessemer converter, is perhaps best answered by the amount of labour required by the two systems. In an audience consisting largely of practical men, I do not apprehend it will be denied, that our present "indirect process" costs in wages, for the smelting and the Bessemer processes, less than one-half the sum paid in converting pig into puddled iron; and probably, we shall agree in supposing that if the reverberatory furnace should have to do the work of the blast furnace, this double cost may have to be doubled again.

In a locality where charcoal appears to cost 60s. per ton, and lignite 12s., but where ore, very suitable for steel making, is valued at 5s. 6d., it is sought to neutralise the disadvantages of coal, dear and unsuitable for blast furnace work, by having recourse to a direct process. To carry out these views a highly carburised bath (*hochgekohltes Metallbad*) of pig iron is made in a Siemens furnace. To this molten pig, melted or highly-heated ore is added, by which the excess of carbon in the fluid metal reduces a corresponding portion of iron of the ore just added. The bath of metal is now to be restored to its pristine state of carburisation by the addition of solid carbon, after which the slag formed is removed and more ore is to be added, and this alternate system of treatment is continued, until the required quantity of steel is obtained.

The cost of 1000 kilos., say one ton, of the steel produced by this modification of the direct process is thus stated by its author:—

				£	s.	d.
Ore containing 52 and 54 per cent. of iron, but yielding 47·4 per cent. of steel	2110 kilos.	@ 5s. 6d.	=	0	11	0
Charcoal	240 „	@ 60s.	=	0	14	4·8
Lignite coal	2000 „	@ 12s.	=	1	4	0
Labour			=	0	11	7·2
Repairs			=	0	8	0
Carburising the metal			=	0	1	0
				£3	10	0

After what has been said, I shall be surprised if an ore containing, say, 53 per cent. of iron, when reduced in such an oxidising atmosphere as that to which it has to be exposed in a Siemens furnace, will be found to yield 50 of steel.* The other expenses do not require criticism, because, even upon the statement given above, the weight of ore and coal used in this direct and single operation is greater than that consumed in the blast furnace and at the converter taken together; the labour is very much higher, and I apprehend that, to the remaining item of "repairs" (8s.), a considerable sum will have to be added for other expenses connected with the establishment. Further, it may be said that the abnormal conditions of the locality are not such as render the process one of general application, even if all the expectations entertained of it by the inventor were realised.

M. Chenot, at the French Exhibition, 45 years ago, was awarded a "*grande medaille d'or*" for what M. Le Play, a scientific French-man of repute, declared to be "the greatest metallurgical discovery of the age."[*] In 1862 it was reported that 2000 tons per annum of bar iron were being made by it in the north of Spain, and I myself saw the process in operation there in 1870. It consisted in exposing a mixture of ore and charcoal in a close retort, heated from the outside. The process continued to be practised some years subsequent to my visit, and it may therefore be inferred that time enough had been devoted to the question to have proved its commercial value, or the reverse. It is now a considerable time since all trace of this discovery was swept away, after having had a very prolonged trial. According to an account given by Dr. Percy, there is a loss of 18 per cent. more ore in obtaining merchant bars by this process than is incurred in the ordinary method of producing this form of malleable iron. The fuel consumed is about the same in both cases; but more than one-third of that used in the direct process being charcoal, the actual cost must necessarily be much the higher of the two.

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* It should be mentioned that in this particular case it is proposed to have the initial highly carburised iron made in the Siemens furnace itself, or obtained elsewhere, most probably, I presume, from a blast furnace. As no pig iron is alluded to in the estimate of cost, it is taken for granted that the entire operation is conducted in the open hearth.

M. Gruner, whose valuable labours on the metallurgy of iron have been universally acknowledged, gives a much more unfavourable account of the Chenot process.[†] According to him, the waste of metal (Fe) upon a ton of finished iron was 45 per cent., and the consumption of fuel amounted to four tons. This calculation does not appear to comprise the power for driving the machinery, so that 4½ tons would be the probable total weight of coal required per ton of finished bar iron.

The consumption of coal for the blast furnace and Bessemer process on a ton of merchant steel does not exceed 2¾ tons, while the actual waste of iron (Fe), instead of 45 per cent., as in the direct process, may be taken at 15 per cent.

In addition to this serious waste of material, there are other inconveniences connected with the manipulation of the product. The iron sponge is so prone to oxidation that, when warm, it takes fire on exposure to the air—a property which compels it to be stored in close vessels. M. Gruner mentions eight days as being thus required for reduction and cooling. If this be correct, sufficient appliances would have to be provided to hold about 2700 tons of the light sponge, in the event of it being desired to rival the production of one of the Edgar-Thomson blast furnaces. Besides this, there will be the preparation of from 3500 to 4000 tons of ore per week, which has to be used of the size of hazel nuts.

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[*] Percy's "Metallurgy," p. 335.

[†] *Traité de Métallurgie*, tome ii. p. 244.

A few years ago, there existed, among the mountains of Savoy, a small blast furnace, making, upon the occasion of my visit, about 25 tons of iron in the week. The fuel was charcoal, and the blast was created by a small stream of water falling down a 12-inch square wooden box, about 15 or 20 feet in height. The water was received in a square closed cistern of wood, by which the air carried down with the stream was separated from the water and driven into the furnace. This was the instrument, but of only half the power of that I saw working, which finally extinguished, ages ago, all the Catalan direct furnaces in almost every part of the civilised world.

In the year 1727 charcoal pig iron cost at Kidderminster £6, 5s. per ton, of which the ironstone cost only 30s., the weekly make being under ten tons. To convert this into malleable iron in a Lancashire fire, as it is called, a further expenditure of £5 was incurred, bringing up the total cost to £11, 5s.

One hundred and sixty years after the date mentioned finds us in England, bringing ore 1000 miles over sea, selling the pig iron made from it at little more than 40s., and disposing of steel rails made from the same pig at less than 75s.

It is against the appliances which have enabled us to perform what may be regarded as a marvel of economy—against the blast furnace, making 1000, and even up to 2000, tons in a week, and one or two Bessemer converters, as the case may be, turning the whole into steel as the metal runs from the furnace, that a process, which has practically made not one step in advance during the last fifty years, ventures, in our day, to wage war.

If there is a spark of vitality in this obsolete plan, what have our ironmasters been about that they have not blown it into life? We have had, and have now, men among them who have distinguished themselves by the manner in which they have taken hold of every sound idea, scientifically propounded or otherwise, and ensured its success, often beyond the most sanguine expectations of the most sanguine inventor. It may well be asked how it is that this direct process has, up to this time, ended in direct failure? Perhaps some one else will endeavour to answer the question, for as regards myself, my fears as to its merits were published sixteen years ago. All that I can add to what was then said is, that its future chance of success must depend on counteracting the obstacles referred to in this paper, obstacles which hitherto have constituted a barrier between every direct process and commercial success.

It has also been proposed to accelerate the direct process, and for that matter a great many other things, by the use of water gas, a form of combustible of which a good deal has been said of late. It is not to be denied that hydrogen gas, forming, as it does, half the volume of water gas, the other half being carbon already partially burnt, may, as a combustible, have an assured value in certain special cases. The hydrogen element affords above four times as much heat as the same weight of carbon, but unfortunately, and unavoidably, it requires more than four times as much carbon to produce it. We might therefore as reasonably expect a hydraulic wheel to pump back all the water which had served to move it, as hope to be able economically to burn any combustible twice over; for that is the impossible problem the water gas makers ask us to accept as possible. It is almost superfluous to say that the same line of argument is more than equally applicable to a proposal to use water gas in the blast furnace, which was also mooted some ten years ago. Its utter unfitness for this office is apparent when we consider that any steam formed by the combustion of hydrogen, and any carbonic acid generated by burning carbonic oxide at the tuyeres, will be returned to their original condition of water gas the next instant after their formation. In other words, heat generated by their being burnt will be entirely absorbed by the return of the constituents to the form in which they existed in the water-gas previous to its combustion.*

While thus expressing a belief that the blast furnace is not destined to be displaced to any appreciable extent by any direct process, I am not prepared to deny that in some special and comparatively unimportant instances it might not be usefully employed, particularly in the case of the rich ores of Lake Superior.

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* It is a remarkable fact that the document recommending this application of water-gas was accompanied by a statement of an actual trial made at a Belgian ironwork, every line of which proved, in unmistakable terms, its complete failure.

A direct process, as is well known, is constantly practised in the manufacture of Siemens-Martin steel, but there its chief value is in effecting the removal of the metalloids found in the pig iron.

What I do think is, that, for the economical manufacture of iron and steel, it will be much easier for the blast furnace to dispense with the direct process, than for the direct process to dispense with the aid of the blast furnace.

In face of the admitted advantages in quality and cost of conversion of ingot over puddled iron, the fact that 2¼ million tons of ordinary malleable iron were made in 1889 in Great Britain may seem, and no doubt is, difficult of complete explanation.

There are several circumstances which conduce to this continued vitality, but into these there is not time here to enter. Possibly the puddling furnace may be employed for many years to come, but everything seems to point to a gradually decreasing demand for its produce. Should the day ever arrive when the labours of Bessemer, or Martin's adaptation of the Siemens furnace for decarburising pig iron, entirely supersede the process of puddling, it must not be forgotten that the world owes to Cort an invention, which, of itself, had enabled us to revolutionise the art of locomotion, by sea as well as by land.

Mention has been made on a previous page of the hurtful effects of phosphorus in pig iron for steel-making purposes. Unfortunately for Great Britain, its more extensive beds of ore were deposited at a geological period, when the prevalence of animal life served to concentrate, in particular localities, the element so much objected to by iron manufacturers. This source of contamination, as it was deemed, appears to have been in active operation during the carboniferous age, and still more so while the rocks of the lias and oolite were in course of formation. Thus it is that the ores, known under the general appellation of clay ironstone, give an iron containing from 0·5 to 2·5 per cent. of phosphorus, derived from phosphates, chiefly of lime, a common constituent in animal bodies. More than twenty years ago it was pointed out how beneficial it would be, if this phosphorus could be eliminated from the iron and laid on our land. We have lived to see this accomplished by the basic process, and, having regard to the growing demand for steel, it is difficult to overrate the importance of extending the area we have to look to for the raw material. Mr. Gilchrist informs me that the quantity of pig iron treated in the Bessemer converter and open-hearth furnace during the year 1889 was close on 500,000 tons in the United Kingdom, and 1,780,000 tons in other parts of the world.

The effects of the presence of foreign substances on the properties of malleable iron and steel are now universally recognised. This observation is more particularly directed to the injurious consequences that often result from the silicon, sulphur, and phosphorus which remain, after the conversion of the pig iron into these two forms of the metal.

On the other hand, the service rendered by carbon in conferring increased strength and elasticity on iron cannot be exaggerated. This fact has naturally led to the inquiry whether other elementary bodies may not assist, either in carrying off hurtful matter, or in increasing the valuable properties just referred to.

Other problems connected with the resisting powers of steel, as they are affected by the manner of cooling, are also occupying the minds of those interested in the question. Among others, Mr. Osmond has contributed important information in a recent communication to the Iron and Steel Institute.

DISCUSSION.

Mr. **GEORGE W. MAYNARD** described a direct process plan now in operation in Pittsburgh, which he stated to be a commercial success. Mr. Maynard said he would take as the text for his remarks Sir Lowthian Bell's final words on direct processes:—

"If there is a spark of vitality in this obsolete plan, what have our ironmasters been about that they have not blown it into life? We have had, and have now, men among them who have distinguished themselves by the manner in which they have taken hold of every sound idea, scientifically propounded or otherwise, and ensured its success, often beyond the most sanguine expectations of the most sanguine inventor. It may well be asked how it is that this direct process has, up to this time, ended in direct failure? Perhaps some one else will endeavour to answer the question, for as regards myself, my fears as to its merits were published sixteen years ago. All that I can add to what was then said, is that its future chance of success must depend on counteracting the obstacles referred to in this paper, obstacles which hitherto have constituted a barrier between every direct process and commercial success."

His answer to the statement that these processes have "ended in direct failure" was that to-day in the city of Pittsburgh a direct process was being carried on at the works of the Carbon Iron Company which was a commercial success. He had watched the development of this process off and on for the past twelve months, and had noted with surprise the success which had been achieved.

For the following notes he was largely indebted to Mr. H. W. Lash, the able general superintendent of the works; Mr. Matthew Graff, the president director; and Mr. Alfred E. Hunt of the Pittsburgh Testing Works, who had done much in the investigation of the process. Attention was called to a description of the Carbon Iron Company's process in a paper written by Alfred E. Hunt, upon "Recent Improvements in Open-Hearth Steel" (p.

708, vol. xvi., *Transactions American Institute Mining Engineers*), and also to a note upon a "Modification of the Reducing Process" used by the Carbon Iron Company, by the same writer (p. 678, vol. xvii.). In these two papers the process was accurately described in detail, and figures and data were given as to the stock used, and the quantity and quality of the output. Mr. Hunt, in his first paper, said:—

"The chief difficulty with all such processes has been, not to reduce the iron and to make wrought iron from the ore direct, but to do this without heavy loss. The Carbon Iron Company uses as a reducing agent (which also protects the reduced iron from re-oxidation), a peculiar graphite from Cranston, near Providence, R.I. It resembles both graphite and anthracite coal, and has about the following composition:—

	Per Cent.
Graphitic carbon	78·00
Volatile matter	2·60
Silica	15·06
Phosphorus	0·045

"The principle of the process is that the peculiar graphite used as a reducing agent does not burn out rapidly, but adheres to the iron in considerable quantities in the sponge, protecting it, and allowing the balls to become compact and solid, so that when they are taken from the furnace they do not re-oxidise very rapidly, but can be squeezed and hammered, or rolled, without a comparatively severe loss. The oxidation in carrying the sponge-balls from the reducing furnace to the open hearth, although the distance be considerable, is almost nothing. In fact, the sponge-balls can be taken out of the furnace and allowed to cool off completely in the air with but very trifling oxidation—less than that upon an ordinary compact bar of iron of the same weight, and heated under the same conditions."

The process, as originally practised with the Rhode Island graphitic carbon, was under the patents of Dr. Eames. The present process, however, was modified in almost every essential principle from the claims in the Eames patents.

1. The novelty of the process as now used consisted in intimately mixing the finely-ground iron ore with pulverised car-

bonaceous material, wet with a wash of lime or some similar inert material, in order to retard the too rapid combustion of the carbon, and thus give time for the dissociation of the iron and oxygen to take place at the temperature necessary for the reduction upon the "protected" carbon or graphite-lined hearth, of an ordinary reverberatory furnace.

2. Each of the sixteen reducing furnaces when in constant use had a hearth lined for about 10 inches deep with either graphite or coke, washed with lime. These hearths were 19 feet long by 5 feet wide. The height of the side walls from the hearth to the skewback of the roof was 22 inches, and the roof had a spring of only 3 inches. The furnace was heated by natural gas, which is admitted at each end, the stack being in the centre of the roof. These furnaces were very durable, and required very little expenditure in repairs. The average life of the furnaces thus far had been at least a year before new side walls and roof were required.

3. Each furnace charge consisted of 2240 lbs. of finely pulverised ore, intimately mixed and ground well together with 600 lbs. of Connellsville coke, which had been crushed to very small particles, and wetted with a wash of milk of lime to "retard" its too rapid combustion.

4. It is very important that the coke or other carbonaceous material should be very intimately mixed with the particles of iron ore. Experience shows that it is only when the ore is fine, and in actual contact, particle to particle, with the solid carbon, that the best results in reduction are secured. Again, the intimate mixture of the ore and solid carbon helps to protect the carbon particles from too rapid combustion, and became itself an "inert retarding agent" for the carbon, in the same way that milk of lime acted.

5. Gas carbon, coke residuum from oil-tanks, and in fact limal oil itself, had been satisfactorily used as a carbonaceous reducing agent, the oil being mixed with the ore in such a way that, when heated up in the reducing furnace, its residual coke, after the volatile matter had been distilled off and burned, was very intimately mixed with the particles of ore, which protected it from further combustion until it had performed its functions of reduction of the iron. These forms of carbonaceous matter were used

with very pure grades of ore, and where stock of a very low percentage of phosphorus was desired.

6. Several patents upon the way of "retarding" the carbonaceous material, the method of mixing the carbon and the ore, and of various carbonaceous materials used as reducing agents under varying conditions, as well as for methods of lining the hearth of the reducing furnace, had already been issued.

7. The iron ores used during the past year had been:—

Minnesota Y ore, 62 to 65 per cent. iron, phosphorus	0.06 hard red ore.
Lake Superior, Section 16, 65 per cent., phosphorus	0.02 hard red ore.
Republic magnetic and specular, 65 per cent., phosphorus	0.06 hard black ore.
Hard Lake Angeline ore, 65 per cent. iron, phosphorus	0.02 hard red ore.
Champion magnetite, 64 per cent., phosphorus	0.05 hard black ore.

8. The time from out to out of a heat was a little over three hours. Three heats were made per shift, and each shift worked between ten and eleven hours, so that six heats were drawn from each furnace per twenty-four hours. The iron sponge was formed on the top of the charge in about one and a half hour's action of the reducing flame, the remainder of the time being taken in balling up the heat, as in the ordinary puddling operation.

9. There were two men employed at each furnace—one furnaceman and one helper. It was the duty of the furnaceman to keep the bottom in good repair, regulate the heat, assist in charging and balling up the heat, and have general charge of the operations of his furnace. The helper assisted the furnaceman in preparing the bottom, charging and balling the heat, attending to the doors, carrying the balls to the squeezer, and looking after the tools.

10. Each charge of 2240 lbs. of 65 per cent. iron ore yield about 1440 lbs. of squeezed sponge-balls, of about 6 inches diameter, and, say, 15 or 16 inches long, weighing from 135 to 150 lbs. each; ordinarily ten balls were taken from each heat. Of course, the regularity of this depended upon the way that the furnaceman balled up his heat. The regularity of yield from all the furnaces in the output was very remarkable, as compared with similar figures of the output of a puddle mill, and was largely due to the more accurate weight of ore than of pig iron charged, and to the fact that it was not so easy for the furnacemen to "steal stock" in order to increase their tonnage as in puddling.

11. The blooms contained, after having been squeezed, about 97 per cent. of metallic iron, and rolled melting bars about 99 per cent. iron. The impurities in the carefully obtained average drillings of blooms and melting bars from the various ores were as follows, as determined by many analyses by the Pittsburgh Testing Laboratory Chemists for the Carbon Iron Company:—

	Y Minnesota.	A Hard Ngeline.	Lake Superior, Section 16.	Champion Magnetite.	Republic Magnetite.	Old Bed Port Henry.	This from mixture of one-half Lake Superior, Section 16, with either Champion or Republic Magnetite Ores the other half.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Phosphorus in blooms	0.040	0.015	0.015	0.03	0.035	0.35	0.020
Sulphur in blooms	0.040	0.03	0.019	0.03	0.03	0.026	0.025
Phosphorus in melting bars	0.015	0.006	0.007	0.020	0.020	0.25	0.010
Sulphur in melting bars	0.040	0.02	0.010	0.035	0.020	0.016	0.015
Phosphorus in ore	0.063	0.02	0.025	0.045	0.06	...	0.035
Sulphur in ore	0.035	0.03	0.035	0.040	0.045	...	0.035
Metallic iron in ore	62.16	65.00	65.00	64.50	65.50	67.50	65.00

The column at the right hand, of the mixture of one-half Lake Superior, Section 16, ore, with either Champion or Republic magnetite ore as the other one-half, was the ordinary mixture that had been used for the last six months, and the analyses of the blooms and melting bars was the average of the analyses of the material produced during the last six months, except in special cases noted elsewhere.

12. The process eliminates from the blooms, with low phosphorus Bessemer ores, at least one-half of the phosphorus in the contained ore, while with high phosphorus ores, fully two-thirds of the phosphorus was eliminated from the blooms, and further rolling of the blooms into melting bar purified fully one-half of the phosphorus remaining in the blooms, thus conclusively proving that the phosphorus still remained as a phosphate in the slag. In fact, the condition of the phosphorus in the blooms was still further proved by the fact that a considerable further elimination of the phosphorus may be secured from the resulting steam ingots by tapping off a considerable portion of the open-hearth slag immediately after the melting of the blooms. The analysis of the open-hearth slag

showed it to contain a considerably larger percentage of phosphorus directly after the blooms had been melted in the bath than later, or when metal had become hot enough to tap. An examination of the temperature of the furnace during the reducing, and after balling, operations would show that at no time was the heat high enough to melt the reduced iron, and there was no doubt that the phosphoric acid in the gangue of the ore was not reduced to phosphide during the process.

The mode of charging either the direct sponge-balls or the squeezed blooms with their initial heat into an open-hearth bath permitted of a much more rapid melt, with all its attendant advantages of improved quality of product, saving of time in melting, and labour connected with charging.

13. The present product of the direct reduction works of the Carbon Iron Company was about one-half sold, and one-half used as blooms to be remelted in their own open-hearth furnaces. Of the amount sold, about one-third, or 17 per cent. of the entire output, was in the form of melting bar to be used in the manufacture of crucible steel, the larger portion of the remaining two-thirds being in the form of blooms for melting in O. H. furnaces.

Mr. Maynard was informed that the present output of the sixteen reducing furnaces was fully up to 1440 lbs. of squeezed blooms per heat, being, with six heats per twenty-four hours, 8640 lbs. per day, and for the sixteen furnaces, 138,240 lbs., or 61 tons per day.

14. The fuel used was natural gas, and it unfortunately happened that the amount delivered to the reducing furnaces had not yet been metered; this would, however, soon be done, when so important a question would be determined. It was assumed that about 13,250 cubic feet of natural gas was used to the ton of squeezed blooms—in other words, the same amount that was used in puddling a gross ton of pig iron.

15. The loss of metallic iron, as claimed by the Carbon Company, was 6¾ per cent., *i.e.*, from the metallic iron in the ore to the metallic iron in the squeezed blooms. Mr. Hunt furnished the following data as sustaining this claim:—Two thousand two hundred and forty lbs. of 65 per cent. iron ore, containing 1456 lbs. of metallic iron would yield 1400 lbs. of squeezed blooms, containing

97 per cent. of metallic iron. This weight of blooms would contain 1358 lbs. of metallic iron, showing a loss of only 98 lbs. of iron, or 6 and $\frac{73}{100}$ per cent. of the total iron in the 2240 lbs. of ore used. The fact that these squeezed blooms contained 97 per cent. of metallic iron was not only determined by the average of many analyses, but also from their yield in steel ingots, when added to an open-hearth steel charge. An average melt of open-hearth steel, pig iron, and scrap would give a loss of about 7 per cent., reckoning the weight of pig metal to be all iron; similarly reckoning charges of 40 per cent. of pig metal, with 60 per cent. of carbon blooms, gave an average loss of between 12 and 13 per cent.—about what would be expected with squeezed blooms of 97 per cent. metallic iron. Similar charges of 40 per cent. pig iron, with 60 per cent. of squeezed puddled blooms, gave a loss of between 10 and 11 per cent., and they had found similar average check analyses of the puddled blooms to show about 99 per cent. metallic iron.

The quality of the steel containing considerable quantities of the Carbon Iron Company's direct made iron, as had been previously stated in the papers on the subject in the Transactions of the American Institute of Mining Engineers, was very superior, and was especially noted for its durability. The following tables showed results obtained by them in regular practice:—

Quality.	Carbon.	Phosphorus.	Manganese.	Ultimate Strength Pounds per Square Inch.	Elongation, per Cent in 8 Inches.	Reduction per Cent.	Test specimens will bend
Dead soft steel .	0·10	0·060	0·40	49,800	36·00	75·00	on themselves 180°
Dead soft steel .	0·11	0·058	0·42	50,600	35·00	72·00	on themselves 180°
Flange steel . .	0·13	0·068	0·45	55,200	30·30	68·00	on themselves 180°
Flange steel . .	0·14	0·065	0·46	56,390	31·00	70·00	on themselves 180°
Soft bridge steel .	0·14	0·075	0·52	58,100	31·00	65·00	on themselves 180°
Soft bridge steel .	0·15	0·082	0·56	60,200	29·00	62·00	on themselves 180°
Medium bridge steel	0·16	0·080	0·53	64,100	29·50	59·50	on themselves 180°
Medium bridge steel	0·18	0.078	0·55	66,900	28·00	58·00	on themselves 180°
High bridge steel .	0·22	0·082	0·58	72,800	25·00	50·00	around pin
High bridge steel .	0·24	0·076	0·60	78,600	22·50	45·60	thickness of test-piece.

Mr. Maynard was not aware that the claim had ever been made by the Carbon Iron Company, or its representatives, that this process was to come in as a competitor of the blast furnace, as intimated by Sir Lowthian Bell. The claim was the production of a uniform and much cheaper material, for the open-hearth and crucible steel processes, than could be obtained in any other way. The high character of the open-hearth steel made by the Carbon Company, and the constantly increasing demand for the squeezed blooms, and bars rolled directly from these blooms, by other steel manufacturers, had practically settled the question of quality.

Professor H. M. **Howe**, of Boston, said that very few people of good judgment could refrain from agreeing with Sir Lowthian Bell's main conclusion, that the blast furnace was more likely to be able to do without the direct process, than the direct process was likely to be able to do without the blast furnace; but he thought it might be a little rash to conclude that, because the blast furnace was likely to hold the upperhand, the direct process might not be very applicable, and more economical under certain conditions. The direct process was likely to remain a much more difficult and complicated process than was the blast furnace process, so that if it were direct, it was, nevertheless, more difficult. It required greater skill, and it required special conditions. Now, it seemed to him a little like the case of an absolute monarchy and a limited monarchy. A limited monarchy was a much more difficult and complicated system of government to carry out, but, at the same time, they thought that it was a much better system. The triple-expansion engine was a much more complicated thing than the single-cylinder valve engine, and yet, under certain conditions, it was the better of the two. The direct process seemed to him to have great possibilities. In a blast furnace they had not only to do the work of the direct process, but a great deal of other work as well. The work of producing iron, they might say, consisted, in the first place, of the chemical work of deoxidising the iron oxide; in the second place, in raising the heat required to raise the iron and the other materials associated with it in nature to a very high temperature. In the case of the direct process (and he did not speak of any one direct process in particular, but simply of the direct process in general), it was not necessary, in the nature of things, that the temperature should ever be above a low, red heat. In the case of the blast furnace, it was hard to see how the temperature could well be less than the melting-point of a very infusible silicate of lime. There he thought that they had a great possibility in the direct process; they needed only a pretty low temperature: in the blast furnace they must have a very high temperature. The direct process called for certain conditions, and he did not see how it could be applicable to lean ores, unless those ores were magnetically concentrated. Another and special condition which favoured the success of the direct process was the existence of a fuel which could be applied to the direct process, but which could not be applied to the blast furnace, and which was much cheaper than any existing or locally available fuel which was applicable to the blast furnace. That at once gave the direct process an enormous advantage, and there were many who wondered whether the success of the Carbon Iron Company's process in the city of Pittsburgh was not in a large measure due to the fact that for that process natural gas could be used, while for the blast furnace natural gas could not be used. There, in the city of Pittsburgh, the Carbon Company's process possessed an enormous advantage which it might not have elsewhere. How much weight could be attached to that point further investigation must determine. As to the loss of iron, was it quite just to say that because the loss of iron had been enormous in some of the direct processes carried out in the past, without the metallurgical knowledge or skill of to-day, it always must remain so? Professor Maynard had given the loss at a point which he thought would strike every one as extremely low. He had had access to most of the data from which Professor Maynard spoke, and he thought it was a little beyond the mark to put it as low as that. From his data he found the loss to be about 17 per cent., which was equivalent to saying that 100 parts of iron ore would yield 83 parts of ingots by the direct and open-hearth processes taken together.

Mr. G. J. **Snelus** said he had had some experience with the direct process very many years ago; for it so happened that the first patent with which he was associated was taken out for him by the late Mr. Menelaus, of Dowlais, for a direct process of making iron. He was also associated with Sir William Siemens in his direct process of making iron at Towcester, he was sorry to say. He therefore thought that he might venture to say a few words in connection with the paper by Sir Lowthian Bell. Of course, they would all admit that the blast furnace was not going to be ousted entirely by any direct process. That they might set down as the first fact, and in that respect he certainly agreed with Sir Lowthian Bell. Where they required pig iron for foundry-work, where they required it for anything with which it was used as pig iron, there, certainly, the blast furnace must always hold its own. He thought, therefore, that for many purposes, the combined processes of the direct process with the open-hearth or the Bessemer processes would always hold their own; but there were, he was sure, very many cases where a direct process of making iron, if it could be carried out economically, would be available and useful. His first experiments on this subject were made some twenty-three years ago, and curiously enough in the presence of a Pittsburgh man, Mr. Thomas Blair, who happened to be at Dowlais at the time, to introduce what was then called the Ellershausen process. That attracted his attention, and he set to work to make a number of experiments upon the reduction of all the iron ores with which he was acquainted. He did it in this way: he reduced the iron ore to a fine state of division, and then took the exact time that was required under the most favourable circumstances to get rid of the oxygen and to obtain metallic iron; and he found that it was possible, under the most favourable circumstances, to reduce the oxide of iron, to get rid of oxygen, and to obtain metallic iron from the iron ore in two minutes. He thought that that was a very important fact to bear in mind; that the hold which oxygen had upon iron in its combination was not of that powerful character, but that, under proper conditions, the compound might be broken up, and the metallic iron set free in a very short space of time. That was one factor for consideration. The exact arrangement which he had patented for obtaining iron by the direct process was the application of the German furnace termed the Gherstenhofer furnace. This was simply a tall vertical chamber of brickwork, in which there was a series of horizontal fire-brick bearers of V-shaped section. The furnace was adopted at Messrs. Vivian's copper-smelting works at Swansea, and he saw it used there for burning the sulphur out of the pyrites. His friend Mr. Thielen, the President of the German Association, was then at the works, and he (Mr. Snelus) went to ask him how far such a furnace was applicable to a direct process of making iron. He was proud to say that that was his first interview with Mr. Thielen, and he had in his pocket-book a sketch which he very kindly made for him of that furnace. He came back convinced that it was an apparatus which could be utilised for the production of iron by the direct process, by reversing the operation. In the Gherstenhofer furnace, when used for calcining pyrites, the air is admitted to burn the sulphur. His idea was to reverse the operation, heat the furnace, and instead of introducing air, to introduce gas, carbonic oxide, or hydrogen. He mentioned the matter to Mr. Menelaus, and he consulted the late Dr. Percy as to its practicability. The verdict of Dr. Percy was that it was entirely right theoretically, but that it remained to be proved by practical experiment how far it would answer. Within a month or two of the taking out of his own patent, he met Mr. Henderson, of the Tharsis Company, who first made ferro-manganese, and it curiously happened that Mr. Henderson had taken out a patent for doing the same thing by the same furnace; and they both agreed at that time that, so far as they could see, theoretically it should answer; but unfortunately the Tharsis Company, having abandoned Mr. Henderson's patent, by allowing it to lapse, it became public property, and therefore it was of no pecuniary interest to Mr. Henderson or himself to push it. But Mr. Henderson gave it as his opinion that it was a practicable apparatus, and that the process might be carried out to success. In that he entirely agreed. Certain ores must be dealt with in the finely divided state. Now, there were large quantities of the finely divided iron ore to be met with. There was a residue from the iron pyrites which they knew in England under the name of "Blue Billy." There were vast quantities of that, but there were large quantities also of finely divided ore in existence in other forms.

But now it appeared that in America they were going to find it necessary to reduce a large quantity of their magnetic ores, which were so abundant in that country, to a fine state of division, for the purpose of improving them by the magnetic separators;

and they were told at New York that separators were now to be put up to treat, as he understood, a thousand tons of ore per day at one concern. If this were so, it was quite evident that a vast quantity of ore in this minutely divided condition was about to become available, and would be better used by some process of direct reduction, where they could get the reducing agent into intimate contact with the finely divided material. What he insisted upon was, that if they applied the direct process, they should deal with the materials in a reasonably fine state of division, and the reducing agent should also be in a fine state of division, or it should be gas. He thought, therefore, while he still agreed with Sir Lowthian Bell that they were not likely to oust the blast furnace, that there was yet a direction in which the direct process might be utilised, and in which it would prove even more economical than the combined processes of the blast furnace and the Bessemer converter or the Siemens open-hearth furnace. When they considered that, as Sir Lowthian Bell had told them in his paper, the theoretical quantity of carbon which was required to remove the oxygen was only 4·38 cwts. of carbon for 20 cwts. of iron, and that the theoretical quantity of carbon required to produce the heat for the process was only 1·27 cwt., making a total quantity of 5·65 cwts. of carbon to produce one ton of iron, it was evident that there was a saving of fuel which was worth trying to attain to, and which he ventured to say in future years somebody would be successful in approximately reaching.

Sir **LOWTHIAN BELL**, in reply, said he did not know that he need detain the meeting very long in replying. He would just say that, so far as the observation from Mr. Snelus was concerned, he himself had had some correspondence with Mr. Blair on the subject of making iron by the direct process. In the year 1874 he visited Pittsburgh, and was taken by Mr. Blair, and most kindly received by that gentleman, and by his partner, Mr. Morrison, to their works in the immediate vicinity of that city. The figures illustrating their process were submitted to him in the most open manner. He endeavoured to the best of his ability to prove to Mr. Blair, by his own figures, that nothing but failure would ultimately attend the process. He was sorry that Mr. Blair did not agree with him; nevertheless, as that meeting knew, further trial showed that this gentleman was in error. Leaving altogether the question of economy out of consideration, which, of course, one could not do in actual practice, and looking at it purely as a matter of chemical reaction, no process that he had heard of appeared more promising than Mr. Blair's. Oxidation from the atmosphere, so far as was possible, was avoided by the sponge being received in an air-tight case until it cooled; and the finer portions of the sponge were mixed with coal-tar, and under very powerful hydraulic pressure was pressed into solid masses before being transferred into an open-hearth furnace in which there was a certain quantity of molten pig iron, in order to produce steel. It was there, as he pointed out to Mr. Blair at the time, that the great loss occurred. His friend, Mr. Maynard, had not told them anything about the loss that was incurred in treating the blooms obtained by this new development of the direct process, which was a most important element in considering the question. With regard to the total fuel required, they must remember that the ground coke which was used in the reducing furnace amounted to 960 lbs. to the gross ton of iron; in other words, they were using in this furnace about one-half of the coke which was required in the blast furnace itself. Then, instead of using about 4 cwt. of coal, as was required for the engines in blowing the Bessemer converter, as he understood Mr. Maynard, nearly one ton of coal for the reduction of the ore was consumed. That was, first, they had 960 lbs. of coke which had to deoxidise the ore, and then they had something like a ton of coal to use in order to enable the coke to reduce the ore. Besides these difficulties, he was surprised when gentlemen talked in the very easy and airy way in which they did of grinding the quantity of ore that they would have to deal with in order to bring that industry into a position to compete with the blast furnace. Then it was said that they must grind the coke so fine that each particle should be brought into contact with its own particle of finely divided ore, and they spoke of that as if it were a thing of easy achievement. He was aware that it was not pretended to dispense entirely with the blast furnace, because for the purpose of making steel it was proposed to melt a mixture of the reduced ore got by the direct process and pig iron. So far, however, as the reduction of ore by this revived method was concerned, it amounted clearly to a superseding of the blast furnace.

On the motion of the PRESIDENT, a vote of thanks was unanimously accorded to Sir Lowthian Bell for his paper.

The following paper was next presented:—

THE PROTECTION OF IRON AND STEEL SHIPS AGAINST FOUNDERING FROM INJURY TO THEIR SHELLS: INCLUDING THE USE OF ARMOUR.

By Sir NATHANIEL BARNABY, K.C.B., London.

We must not conceal from ourselves that, against the perils arising from perforation of the shells or hulls of ships, we are greatly worse off in these days of steel and iron than we were when our ships were built of oak, teak, and pine.

Apart from the greater risks arising from increased speeds, and increased momenta in collisions, the material of which the hull is composed submits so easily to perforation that the writer has numbered among his coadjutors in his profession eminent men who were strongly opposed to the abandonment of wooden bottoms both in commerce and in war.

We have it, on the authority of Lloyds' surveyors, that about one-fiftieth of the value of the vessels in the mercantile marine is required annually to make good losses and repairs entailed by collisions alone.

When the bottom of a wooden ship is struck in a collision with another vessel, much of the force of the blow is expended in bending and breaking the fibres of the wood, and the blow is gradually absorbed, with but little permanent displacement and but little admission of water.

In an iron or steel ship, the bottom may be pierced and permanently displaced over large areas without any feeling of shock in the ship giving the blow.

But despite the local weakness of the material forming the side, and the care it requires to prevent corrosion in salt water, its good qualities have secured its wide adoption.

Long steamships cannot be built of wood. Steamships built of wood cannot be secured against premature decay; they cannot be built quickly without the certainty of rapid decay; the risk of fire is always serious in them; and, except in very small vessels, high speeds are impossible.

The ships in use and building for commercial purposes on the western side of the Atlantic are still constructed generally of wood. The large sailing navy of the United States may be said to consist almost exclusively of wooden ships.

America possesses nearly one-sixth of all the wooden sailing-ships of 100 tons net and upwards in the world; and she will probably find it to her advantage for many years to come to continue to build such ships of wood.

Of iron and steel sailing-ships, Great Britain owns considerably more than three-fourths of all that exist.

When we come to the steam mercantile marine, we find that the United States has as many of her mercantile steamships, of 100 tons gross and upwards, built of iron and steel as of wood.

There can be no doubt that both here and in Canada you must follow the example of Great Britain, and build steamships almost exclusively of iron or steel.

It is the one prominent defect in iron or steel ships that I propose to consider, and that only, viz., the readiness with which they submit to perforation in collisions.

Security against risks of fatal disaster, on this account, depends very little, if at all, upon the thickness of the bottom plating or the closeness of the ribs. The advantage of a steel plating of one inch in thickness over another of half an inch would be very doubtful; and closeness of frame-spacing is not much more valuable.

When open-hearth steel was first employed for the outer bottoms of ships, with a reduction of some 25 per cent. in thickness as compared with iron, it was supposed that the structure would be found to be lacking in rigidity.

In 1877, Chief-Engineer King, of the U.S.N., commenting on the first of such ships, thought that for a ship 300 feet long, and of 3700 tons displacement, and having a double skin, ½-inch steel bottom plating was too thin. He considered it doubtful "whether the hulls would have the strength to endure, for any length of time, the immense strain of 7000 indicated horse-power."

Engines of 9000 horse-power are now put into sea-going steel vessels of 3000 tons displacement.

Experience has amply justified the strength of the material under all strains. One of the two vessels that Mr. King saw ran aground badly in the Mediterranean and suffered no structural injury.

A vessel of the same class—the *Leander*—having similar scantlings, had the misfortune at the outset of her career to be rubbed very hard indeed against the "Hornet Rock." This experience taught us that not only is there advantage in thinness in plating, in the event of collision or grounding, but there is advantage also in light framing within and adjacent to the plating.

In grounding, the frames and bottom plating of this ship had been forced in over a very large portion of her length, and there was a permanent indentation of one foot between the frames. The positions of the frames were indicated like the ribs of a starved horse, but there was not a crack in the plating, and the riveting of plating and butts remained sound. There would, apparently, have been no leakage into the double bottom had it not been for these stiffening frames. Where they crossed the plating there were rows of rivets to connect them with the bottom plating. The frames had been forced in like the plating, but they had permanently buckled, since they had no other way of submitting to displacement. When the plating recovered itself and came towards its original position, it broke the countersink off the rivets, and provided admission for water.

It appeared that, few as the frames were, it would have been better, under these circumstances, if the stiffening had been effected exclusively by bulkheads and longitudinal frames.

Security in an iron or steel ship against fatal injury, arising from the perforation of the shell under water, depends upon two things only—size and subdivision.

Pumps may be dismissed at once as being practically useless in cases of collision in iron and steel ships. No pumps will deal with a continuous inflow of water of even less than half a square foot in area coming through a hole well under water.

Apart from the perfection of subdivision, size is in itself an element of safety. A ship of small or moderate size is sometimes completely severed at the point of striking by the blow of a larger ship.

I am supposed by some persons to object unduly to large ships.

But I confine my objections as to size to ships of war in a powerful navy.

I believe that a large naval power, having very widely spread interests, and subject to modern modes of attack, would suffer more in a war from fewness of ships than from comparative smallness of size of ships and of crews.

I have never thought that size is a disadvantage in merchant-ships, supposing they can be worked financially. On the contrary, the advantages arising from size in passenger-ships seem to me to be so great, that I do not see where we shall stop.

If it were necessary to increase the draught of water, as we increase the length and breadth, that would impose a fatal bar to any considerable advance upon present dimensions. But there is no such necessity. By the use of several engines, working side by side, and suitable propellers, the draught of water of 26 feet need never be exceeded.

I was consulted some years ago by a business man, well known on both sides the Atlantic, as to the possibility of building a steel ship which would not roll, or pitch, or heave in the sea, and in which, therefore, the bulk of passengers would be in a less desperate hurry to get ashore. He thought fifteen knots an hour sufficient speed.

It appeared to me to be perfectly practicable with a draught of water of 26 feet.

I thought the minimum length and breadth would be 1000 feet long and 300 feet broad. I estimated that with engines of 60,000 horse-power, an ocean speed of fifteen knots could be obtained.

Two sets of apparent difficulties had to be overcome, viz., those connected with the building of the ship afloat, and those relating to receiving and discharging cargo. The ship would be a steel island, incapable of entering any docks. The building difficulties soon disappeared. They had no real existence.

To meet the other difficulties, I proposed to form shallow, still-water harbours or docks within the ship, entered by gates in the sides, and to carry, always afloat there, the loaded barges and tugs; turning the barges out and taking in fresh ones already loaded at the ports of discharge and shipment.

Such a ship would require to be fortified and garrisoned like a town. She could be made absolutely secure against fatal injury arising from perforation. The subdivisions required for this purpose might be made to serve effectually against the spread of any local fire.

I do firmly believe that we shall get the mastery over the seas, and shall live far more happily in a marine residence capable of steaming fifteen knots an hour than we can ever live in seaside towns.

The question whether we shall effect our conquest by mere size, or by mechanical devices, in ships of more moderate proportions, depends upon the success of certain efforts which are now in progress in another direction.

In these efforts there have been three stages:—

First, there were the observations by the British naval constructors at the Admiralty, that when a gun, or water, or other loose weight is moved about violently by the rolling of the ship, these movements of the loose weight tend to bring the ship to rest.

The phenomenon is fully discussed in the *Encyclopædia Britannica*, article "Shipbuilding." The physical conditions have been briefly stated by one of the Admiralty officers as follows:—

Explaining the effect in a model of a moving weight representing 100 tons bringing nearly to rest almost immediately what represented a vessel of 10,000 tons, he says the same effect must always occur in a rolling ship if we have a loose weight of any kind, whether the weight be water or a gun. If this reduction in rolling did not take place "we should have something to explain which would be quite inexplicable. For, suppose we have two ships, alike in all respects, as regards size, shape, weight, time of oscillation, &c., and situated on precisely the same seas, but one having all her weights properly secured, and the other with a weight capable of traversing the deck every time the ship rolls, if the two vessels were to roll to exactly the same extent, we should have the sea not only rolling the ship with the loose weight to the same extent as the ship with all her weights fixed, but the sea would, in addition, be doing all the work involved in the traversing of the heavy weight across the deck, which is quite impossible under the circumstances of perfect similarity supposed. The sea can only do the same work on both. In the one case, the work consists entirely in rolling the vessel; in the other, it consists partly in rolling the ship and partly in dashing the weight about. The rolling in the latter must, therefore, inevitably be less than in the former case."

This principle is now applied by constructing water-chambers above the shot-proof decks in the larger ships of H.M. Navy.

But by this system a certain amount of rolling is required in order to start and work the rolling quencher; and something further is needed in passenger-ships.

It is desirable to have a more delicate appreciation of the first tendency to rolling, and an instant application of the quenching apparatus.

The next step was taken by Mr. Beauchamp Tower, an able English mechanical engineer. He contrived a mechanical watchman dependent upon a long pendulum indication. This watchman has sufficient power to control a small platform carrying a gun or other instrument. In a heavily rolling ship the watchman keeps this platform and its load level and at rest. (See *Transactions of the Institution of Naval Architects*, 1889.)

The third step has been taken by Mr. Thornycroft, of torpedo-boat fame. He also makes a mechanical watchman, differing from Mr. Tower's, and dependent upon two pendulums, one long and one short. This watchman is capable of controlling a large movable weight. Mr. Thornycroft describes his plan as follows:—

The controlling apparatus depends first on a pendulum, or its equivalent, having a short period compared with the natural period of oscillation of the vessel to be steadied, or of the waves on which the vessel floats.

A second pendulum, or its equivalent, having a long period, compared as above, and a large moment of inertia, is adapted to join in control with the short pendulum, and more or less balance its tendency to reduce stability when the vessel is inclined.

The steadying apparatus comprises a heavy movable weight fixed to a shaft in such a manner that it places itself automatically, when free, in the fore and aft position. It is controlled by a hydraulic motor, capable of turning it to one or other side of the centre line of the ship, as may be necessary to balance a turning moment exerted on the vessel by waves, or to prevent or lessen the rolling. The distributing valve of the motor is controlled by the pendulum apparatus above described.

It is proposed to employ a movable weight of about 12 tons for a vessel of 250 to 300 tons displacement. Its range of movement would be such as would transfer the centre of gravity of the weight through a transverse distance of 6 feet.

If this third step is made successfully, and Mr. Thornycroft's plan is applied to passenger-ships, there will be no necessity for pressing forward large ships in advance of their due time.

I think we may assume that for some years to come we shall only have to deal with ships which can be built upon the land and launched into the sea without extraordinary risks—ships like the *Oregon* and the *City of Paris*, and subject to the same dangers as those ships from collisions and injury to bulkheads.

Those who are familiar with the history of the accidents to these two ships will have realised the fact that good internal subdivision saved the passengers in the former case, and much better division the ship and passengers in the latter.

When an iron or steel ship is sunk by collision, it is sometimes mistakenly said that the ship had a number of bulkheads or divisions, and that, since these failed to keep her afloat, it matters little whether bulkheads are fitted or not.

It often happens that a ship is sunk when only a comparatively small hole is made in a single compartment. The badly arranged bulkheads do not even delay the sinking. The water spreads itself differently owing to the presence of the bulkheads, but that is all. Instead of levelling itself from end to end throughout the ship, and gradually rising all fore and aft, the water first fills one compartment, then finding the top of the partition separating it from the adjacent compartment has been brought below the level of the outside water, it proceeds to fill that compartment, and so on.

In the year 1866 this question was fully debated by an influential committee of naval architects, shipbuilders, shipowners, Lloyds' surveyors, and sailors. That committee was the Council of the Institution of Naval Architects.

That Council decided that no iron passenger-ship is well constructed unless her compartments be so proportioned that she would float safely were *any one* of them to fill with water, or be placed in free communication with the sea.

They recommended that all iron ships should be so divided that not only the one largest compartment, but *any two adjacent* compartments might be given up to the sea without sinking the ship.

The second is an advisory clause, the wisdom of which is not disputed. The first is condemnatory of badly constructed ships.

No deliverance of any kind has been made during the twenty-four years which have elapsed questioning these important decisions. Yet they are absolutely ignored by everybody concerned, and all iron and steel sailing-ships built since then, and the great bulk of steamships, have been built in disregard of the recommendations of that Council; and in so far as they are used for carrying passengers or emigrants, all these ships have been, and are, in the judgment of that Council, badly constructed.

It is quite true that there are water-tight bulkheads, one or more, in every such ship; but they exist for structural purposes only, and not to carry out the view of the Council, or to prevent the foundering of the ship when run into.

Sailing-ships generally have but one bulkhead, and that right forward. Some—a few—owners have added another "collision" bulkhead aft; while others again, with the desire to provide extra safety from foundering, have introduced one or two others in addition to these two "collision" bulkheads. But these are merely so much deadweight—adding, of course, to the strength of the ship—they would not appreciably alter the time of foundering, if the ship were struck anywhere between the two end bulkheads. They do not go far enough to satisfy the necessary conditions.

More than fifty British sailing-ships of 600 tons and upwards exist having more than two bulkheads—in some cases as many as five or six bulkheads. Of these, fully 23 per cent. are steamers which have been converted into "sailers," and in which the then existing bulkheads were not disturbed.

The highest number of bulkheads believed to be built in any existing sailing-ship proper—that is, an "unconverted" vessel—is four, and these cannot be placed so as to materially alter the time in which a vessel would founder if struck in any compartment.

It must be generally understood that records in registers and examination by surveyors referring to bulkheads in steamships give no security in respect of the fulfilment of this most important condition.

I am contented here to state the facts.

In 1876, ten years after the publication of the views of the Council of the Institution of Naval Architects, only two or three owners of steamships made it the rule to build their ships on these principles.

In the years 1881–1883 there were lost, from various causes, within twenty-one months, one hundred and twenty British iron steamships. Every one of these was in the condition that they had a single compartment the filling of which would have caused the ship to founder.

Last year there was added to the British Register about 1,000,000 tons (gross) of steamships. Of these, not one-third could lay claim to have been built with any intentional and satisfactory regard to safety by means of watertight bulkheads.

The bulk of the well-divided steamers included in the small minority referred to above come under the rules of Lloyds' Register Committee of 1882, when it was happily decided that steam-vessels 280 feet long and above, proposing to pass their survey, must have a certain number of efficient bulkheads, increasing in number as the ships increase in length. Seeing that this Register is a voluntary association with no statutory powers, I think it has done as much as it could in the right direction.

In entering upon the great contemplated expansion of iron and steel merchant shipping upon this side the Atlantic, it may be hoped that you will treat the views of the Council of the Institution of Naval Architects with more respect than they have been treated in Great Britain.

The question of material has been settled for you. The troubles we had with iron on our side are a matter of history.

In 1874 we were giving for iron ship plates of about 7½ cwts. each, delivered at Portsmouth Yard, over £20 per ton (with a scale of extras, from 3½ cwt. upwards, per half-hundredweight).

These plates were tested by resident inspectors at the iron-works. This had been found to be necessary, as inspection at the ship's side prior to acceptance had been found to cause vexatious delays, and heavy rejections after such delays, so that there was often a paralysis of work with both ironmakers and shipbuilders.

This being the condition of things in 1874, a Naval Committee was appointed to consider the causes of the rapid deterioration of boilers. This Committee visited Portsmouth, and reported that it was necessary to secure a better quality of iron. They said that "the rapidity of deterioration of boiler plates and ship plates is greatly dependent upon the purity of the iron, which can only be obtained by increased expense of manufacture." They recommended the payment of higher prices than £20 per ton for 7½ cwt. plates.

It was then determined to meet the increased cost of bottom plates recommended, by using for inferior purposes untested plates, *i.e.*, plates bought on the faith of the "brand" of the maker. Such "branded" plates were at that time employed for all purposes in ships built under the survey of Lloyds' Committee.

Here we had a curious experience which satisfied us that if we could once get material of definite manufacture, and precise and easily recognised qualities, wide competition would speedily equalise prices.

We took ten prominent makers of iron plates, and secured delivery of "branded" plates to an identical specification. The plates were about 7½ cwt. each.

The plates were delivered at Chatham, and were then tested and examined by me, with the following results :—

Prices of 7½ Cwt. Untested Iron Ship Plates in 1874.

Cost per Ton.			Quality of Material.	Condition of Surfaces of Plates.
£	s.	d.		
9	13	0	Strong, but harsh.	Two-thirds unfit for use for shipbuilding.
9	4	0	Strong, but harsh.	Two-thirds unfit for use for shipbuilding.
17	12	0	Strong, and fairly ductile.	Good.
18	2	0	Strong, and fairly ductile.	One-fourth unfit for use for shipbuilding.
9	13	0	Irregular in strength; fairly ductile.	All unfit for use for shipbuilding.
22	12	0	Good.	Good.
12	2	0	Strong, and fairly ductile.	One-sixth unfit for use for shipbuilding.
19	3	0	Weak, and not ductile.	Good.
9	15	0	Fairly strong; ductile.	One-sixth defective.
12	13	0	Strong; ductile.	Good.

In all these cases the extras for breadths over 4 feet, and lengths over 12 feet, raised these prices still higher, or involved the cost of fitting and riveting small plates.

Now, in 1890, you have a perfectly regular material, stronger and more ductile than any of this iron, with no trouble as to surface-blistering and lamination. You can get Siemens plates of 20 cwt., almost without extras for any increased size, delivered at the ship's side at less than £8 per ton. It has, unfortunately, been as low as £6, 5s.

This change from iron to steel was not made without a vast amount of anxiety on the part of responsible engineers who led the way.

The result may not be altogether pleasant to the iron and steel makers. To the shipbuilder and engineer it calls for ungrudging acknowledgment of indebtedness to two eminent British subjects, Bessemer and Siemens, and for the grateful recognition of the enterprise and skill of French, German, and British makers.

We all owe Germany a lasting debt of gratitude for the birth and training of that true prince—William Siemens.

In modern ships of war the main use of armour in the formation of shot-proof decks adjacent to the load water-line, and of more or less complete belts of side armour combined with such decks, is to protect the machinery and magazines from shot and shell.

There has been a wide abandonment of side armour founded upon the recognition of several facts:—

1. The increasing penetrating power of the gun. The 12-inch gun is now more than a match, at close quarters, for the best 18-inch steel plates. It requires the best 9-inch armour to keep out steel projectiles from the 6-inch gun at short range.

2. The great volume and accuracy of shell-fire makes the original arrangement of broadside ports in an armoured side inadmissible. The crowding of men in the rear of an open or unarmoured port can no longer be accepted.

3. The propelling machinery and the magazines are of more consequence than the whole battery of guns, because the ship has become, by virtue of her ram and torpedoes, a powerful fighting machine apart from her guns.

4. The large use of side armour, by reason of its weight and cost, limits the number of ships obtainable with a given sum of money.

But while side armour has been largely suppressed and superseded for these reasons, it still possesses one great advantage. It prevents the entrance of water into the zone between wind and water through holes made by light projectiles not capable of perforating armour, but capable of damaging seriously an unarmoured side.

Those who have appreciated most keenly the value of side armour at the water-line, for preserving the floating power of the ship against light guns, have sometimes failed to see that my apparent unreadiness to concur with them has arisen from real sympathy.

My contention has been that all armed fighting-ships present equal claims to be kept afloat against the attack of the guns which they have to face. I consider that in all such ships the first duty of the designer is to enable the crew to inflict damage on the enemy. Arms and mobility, therefore, come first; endurance under gun-fire next. There must be degrees, varying with the size of the ship, in the strength of the arms and in the amount of the mobility. But all the fighting-men, except those in forlorn hopes, are equally entitled to a chance of existence under the artillery fire which they must receive and endure. I have been unable to understand the exclusive claim for protection by means of side armour in a particular class of ships in a large navy, such ships not being distinguished by exceptionally large crews, nor as being centres of operation for a fleet, nor as being required to attack fortresses. And the question as to the use of belt armour in classes of ships not distinguished as above is perplexed by the following considerations:—

First, and generally, whether, in strengthening the water-zone by side armour against feeble projectiles, we do not expose it more to the very serious attack of larger ones than it would be if formed with an armoured deck near the water.

Secondly, whether with a ship of given size and cost we are not sacrificing active offensive qualities for the sake of a passive defensive quality. Speed of ship, power of armament, or stored-up capital (expended in the ship) may be made to pay too dearly for a passive defence against the invasion of water at the water-zone, seeing that the invasion of water beneath that zone becomes a more imminent and more serious peril to the State in proportion to the reduced speed and the increased cost.

So we arrive at an alternative arrangement, a solid raft-body at the water-zone in place of side belt armour.

It appears that such a raft-body can be made which, when undamaged, weighs with its casings not more than one-third the weight of water, and which, when saturated, does not exceed the weight of an equal bulk of dry fir.

Such a system of water-line defence may prove suitable for all fighting-ships, large and small, by reason of its lightness and small cost. As I understand the position, it is proposed to give a trial to this system in the Navy of the United States.

I think the time is coming, if it is not already come, when there will be a demand, not only for the recognition of the equal claims of all fighting-ships to be kept afloat against the attack of the guns which they will have to face, but also that their crews between decks should be equally protected against the overwhelming effects of the bursting of high explosives there.

For belt and battery armour it is still a matter for debate whether the process of manufacture first introduced, and since most successfully developed, by M. Schneider, or that subsequently devised and manufactured in Sheffield, is the better.

After this paper has left my hands, and before it will be read, there will probably be an interesting series of trials of armour on both plans in the United States; what I say may therefore be very brief.

Both systems have been in open competition from the beginning, and gun-trials have been made by all the maritime powers.

The experience of the Sheffield compound armour-plate makers as to their own manufacture and that of their rivals has been very great. The amount of steel-faced armour which has been manufactured by them, or by their licensees, during the last twelve years, together with that which is in process of manufacture, equals 112,000 tons.

They urge several considerations in favour of steel-faced armour. They say that steel armour cracks through under blows which are not sufficiently powerful to perforate the plate. They consider that the manufacture of steel armour is less uniform and certain, because it is of very great importance to oil-harden and anneal such armour; and these processes are not required for steel-faced armour. They point out that this treatment can only be applied commercially to large and awkward plates with great risk, expense, and difficulty, and that under these circumstances a good test plate offers no security as to the quality of the plates it represents. It is conceded that hard-faced armour endures better under oblique blows. They say that a cubic foot of steel armour weighs 492 lbs., whereas a cubic foot of compound armour weighs only 480 lbs.—a difference of 2½ per cent. in favour of the latter.

An experiment has recently been made in England to ascertain whether it can be confidently stated that oil-hardening and annealing, or some equivalent finishing process, is necessary for steel plates. Messrs. Brown and Messrs. Cammell, the two great Sheffield firms, makers of compound armour, are satisfied as to this necessity.

A 9-inch plate of steel was manufactured and cut into two plates each 4 feet square. One piece was left untreated, and the other was oil-hardened and annealed. They were fired at by the 6-inch gun with Firth steel projectiles weighing 100 lbs.

The striking energy of the blow upon the untreated plate was 2389 foot-tons, and the energy of the blow upon that which had been treated was 2378·5 foot-tons. In the latter case the projectile made an indent of 10·5 inches, so that light was just visible through the centre of the bulge at the back of the plate. The projectile rebounded, broken into three pieces. The plate was cracked through, but was whole, and no material was splintered out at the front or back of the plate.

In the case of the untreated plate, the shot passed through, and the splintering of the steel round the hole in the front of the plate spread over a space 15 inches across. The splintering round the hole at the back of the plate covered a space 33 inches across. The plate did not remain whole, but went into six separate pieces.

I am myself no lover of armour. As a member of a great and peaceful trading community, I dislike everything which, by differentiation, tends to lower the comparative fighting value of armed mercantile ships. I dislike also that which reduces the available number, by increasing the individual cost, of ships of war.

There is, I think, no such necessary and vital distinction between the man-of-war and the properly armed and protected state auxiliary of high speed as would justify the neglect of such auxiliaries for maritime warfare. One must admit that at present there are very great differences between them in fighting value, ship for ship, due partly to the very superior subdivision, and partly to the use of armour of high quality in the regular ship of war.

The man-of-war proper will probably never abandon the use of armour. We may rather expect that steel and steel-faced armour of the highest quality, instead of being confined to a few ships, called battle-ships, will be employed universally for the defence of the absolutely vital parts of every ship built expressly for war service.

DISCUSSION ON SIR N. BARNABY'S PAPER.

Commander F. M. **Barber** said that Sir Nathaniel's paper opened with the observation that the difficulty in stopping leaks in iron ships was far greater than it was in wooden ships. He was right about that, and they had not got over the difficulty yet. In the old times, in a wooden ship they had two or three very simple methods of stopping a leak. They had the old-fashioned shot-plug, which looked very much like a loaf of Martinique sugar, that they could drive into a shot-hole of any size, and it would close it up. They also had lead, and felt, and plank, which they could nail on to the sides of the ship. They had also a method of flowing oatmeal and sawdust into a seam, which would fill it up. But none of those methods would work in a single-skin iron ship. In those vessels they were obliged, for local injuries, to resort to a number of devices which were too frequently unsuccessful. The hole in an iron ship was always smooth on the outside, and rough on the inside, and they frequently could not get at it on the outside; and so the difficulty of making a tight joint was almost insuperable. One of the methods adopted was to use felt and mats; another was an umbrella-shaped affair, pushed out of the hole, when the pressure of the water immediately spread it over; and they also used canvas, weighted so as to go over the side, or a big canvas sail hauled under the ship. But with regard to a long leak in a seam where the rivets had started, it was almost impossible to close it.

Apart from that, the first essential portion of the paper was where Sir Nathaniel spoke of the large size of vessel which he would propose, or had proposed, to build. That was to him a very interesting proposal, because it was quite feasible; only he thought that if the *Great Eastern* with 24,000 tons displacement was of no use, then this vessel, with over 100,000 tons displacement, would be equally useless, if she did not have very great speed. He thought that the vessels which Sir James Kitson spoke of a short time ago would do away with this vessel's business in the way of freights in no time; for in vessels of her dimensions, it took so long to load them, and so long to make a voyage across the Atlantic, that, with an ordinary steamer, they could make half-a-dozen trips in the same time. Farther on, Sir Nathaniel referred to injuries to the bulkheads of vessels, and after some discussion he mentioned the type of bulkheads which had been adopted by Lloyds' and others, as required; but he thought that Sir Nathaniel omitted to state the most essential features which modern practice had brought about in connection with bulkheads. It was of no use to have bulkheads unless they were high enough to go above the water-line when the compartment was full, for they could easily understand that if she went down by the head, the water could flow over one bulkhead; it would then flow over the next one in succession, and finally sink the ship. In the next place, a water-tight bulkhead was of no use unless it really was water-tight. That was perhaps an Irishism, but he meant that it all depended upon that; and that all doors and holes through the bulkheads must be avoided. His friend cited the *Oregon*, and stated that that ship could have saved her passengers as well as the ship if the vessel had had tight bulkheads. But he believed that it was brought out in the court in England that one of the water-tight doors was open—that in placing the cargo they had left the door open.

The next essential feature in that connection (and one which Sir Nathaniel had omitted) was the fact that they found that all men-of-war now, and all of the largest merchant steamers, had twin screws, which enabled them to get bulkheads fore and aft, right through the ship, and that created a long subdivision, which was of primary importance, because after that they only needed to subdivide into smaller spaces. On page 45 (near to the bottom), Sir Nathaniel spoke of the distribution of armour plate. That was a subject which he had hoped to illustrate by some drawings of line-of-battle ships which were now on their way from the U.S. Navy Department, but had not yet arrived. In a few words, however, he might say that the matter of the distribution of armour had largely been due to the development of artillery. In the old days of smooth-bore guns, a four inch armour plate was enough to keep out any projectile, and it was put all over the side of the ship. When they got to rifled guns and greater projectile energy, it was necessary to increase the thickness. They had then to reduce the area, as naval construction allowed only 20 or 25 per cent. of the displacement of a vessel for the armour. They must keep this in mind. They had to thicken it up, and naturally they thickened it over the vital parts and maintained a heavy belt along the water-line fore and aft. But very soon it was found that they could hardly get it thick enough there, and then they introduced what they called the protected deck, below the water-line, and now the armour line was mostly confined to the centre of the ship. On another page, Sir Nathaniel spoke of the water-line of the armour being penetrable by the larger projectiles. He thought that Sir Nathaniel made a mistake in that, because in U.S. battle-ships they had 18 inches of heavy armour, which was exactly what the English had on the largest battle-ships that they were now building, and he should think that that would practically keep out any projectile. The chances at sea were very much improved for the armour, and very much diminished for the gun. It was said by able English artillerists that armour doubled itself when it went to sea. He had been so fortunate as to be at the bombardment of Alexandria, and not one of the vessels engaged there was penetrated through her armour, although there were many guns on shore that could do it, and they were struck many times. He believed that Sir Nathaniel made a mistake where he said that large men-of-war were not useful, for he (Commander Barber) thought that the 14,000-ton ship, as made in England now, represented the maximum of power. They could not get all they wanted, unless they got that displacement as well.

There was another matter in connection with this armour which he thought looked well for the future. He thought it looked as though they were going to be able to break the projectile anyway. The introduction of nickel-steel armour-plate had made a very material difference in that respect. In order to illustrate what he meant by that, let them assume that the projectile energy necessary to penetrate a wrought iron armour-plate was considered as 1. Then the English Government reception test would be represented by 1·07 or 7 per cent. greater; while the projectile energy which they used at Annapolis the other day was 17 per cent. greater; and he had seen at Creusot a nickel-steel plate fired at with a projectile energy of nearly 30 per cent. greater, and the plate did not crack, and the projectile did not get through. There was a possibility of hardening the nickel-steel armour to a degree that they had not reached, while maintaining its tenacity, and as long as they did not crack the plate, there was a possibility of stopping holes, for they could plug them. But when the cracks passed from one hole to another, they could not do it—that was, provided the cracks went clean through. Sir Nathaniel had spoken of a solid raft-body at the water-zone, in place of side-belt armour. That was just now a most interesting thing in connection with the construction of men-of-war. They found that when the gun got so strong that it was almost impossible to keep the projectiles out, the next thing to be tried was to stop the inflow of water through the hole made by the projectile. The French were the first to go into that. They had carried out a large number of experiments, and had adopted a material called cocoa-cellulose, which was made from the hair of the cocoa-nut. The war vessels were built double-skinned, and this stuff was packed in tight. It was very light, weighing but 8 lbs. per cubic foot, and costing but 17 cents per pound in France. This tight filling was so wonderfully absorptive of water, and so expansive, that when a 10-inch shot went through a 2½ ft. belt of armour, the hole would close before half a dozen barrels of water could get through it. The French required that this hole should stay tight for eighteen hours, as they thought by that time they could get to the inner skin and put a patch on the inside, and then they were all right. The difficulty with that kind of material was that it went on absorbing water, and it was necessary to subdivide the double skin of the ship by vertical compartments, which added to the weight. They must confine the flow of water to a short distance; and those vertical bulkheads added to the weight very materially, and were considered bad.

The next step that was taken in this direction was to have these raft-bodies which Sir Nathaniel spoke about, and which were used in all men-of-war now, over the protective deck, the latter being a curved deck, which went 4½ feet below the water-line along the side of the ship from bow to stern, and came up about amidships. All the machinery and all the essentials were beneath that; and if they could keep the water above that, and from getting below, the vessel would always float. So the plan now adopted was to fill in wherever they could above this deck with a material which would obstruct the water—which did not absorb the water, but would obstruct it. In England they had a material which was called "woodite," referred to by Sir Nathaniel as a substance that weighed only 21 lbs. to the cubic foot, that was made of cork and rubber, and was intended to occupy that space. The French were using cellulose, which was made up into cubes and covered with lacquered paper, and weighed 8 or 9 lbs. per cubic feet. These would stop the water, or, if the water penetrated, would keep it from circulating around. The French Government, the Greeks, the Japanese, the Russians, and one or two other nations had also made use of the cellulose. The English Government had never made use of anything of that sort. Their experiments with cellulose were not satisfactory. The French seemed to have got rid of those difficulties. Although the woodite was of English manufacture, the English Government did not use it, whatever they might think of it. In the United States they had adopted cellulose. The application of that material to a man-of-war was quite simple, but when it came to a merchant ship, he questioned very much if they had not got to advance a great deal further in connection with machinery, &c., before they could afford to have a merchant ship with a double skin all around. It took too much horse-power to drive it; but when they did have that material filled in, it would add very materially to the life-saving and life-preserving qualities of the ship.

Sir Nathaniel had further discussed the subject of steel and compound armour, giving the compound armour a preference. It was of no use to discuss that matter now. What Sir James Kitson had said that morning about nickel-steel sufficiently covered the case. He thought that that was a thing of the future, and as he had said that a London syndicate had covered all the patents on it, it was likely to see a very great future. He would like to say this, however, in connection with the matter of the development of homogeneousness in armour in England. He did not think their manufacturers had ever had very much of a chance, on account of a ruling of the Admiralty. They all knew that if steel were struck very hard it would crack, and that the crack would go clean through. In compound armour, which had one-third steel face and two-thirds wrought iron, the cracks only ran in. The English Admiralty had always been very stubborn about that matter, and never would allow the cracks to go through. The result was that a steel manufacturer never had any chance with the Admiralty; he was thrown out of court every time. The French Government induced different manufacturers to take up the manufacture of compound armour, and they afforded a great deal of encouragement to steel. They admitted the through cracking, and undertook to compensate for it by an increased number of bolts to hold it on to the side of the ship, and as long as it stayed there they considered that that was what they wanted. The result had been to develop a system of bolting which he thought was superior to any other. They employed a large number of small bolts, which worked better than a small number of larger bolts. The armour trials which they had at Annapolis some time ago pointed very plainly in the direction of nickel-steel. He thought from what he had seen of it that it could be developed much better than had been shown there. He had had something to do with those experiments, and if any one would like detailed information, he would be happy to give it them at any time during their stay there. Sir Nathaniel gave his opinion as to what should be the disposition of the armour on men-of-war, holding that every ship which was intended for fighting purposes should have armour on it. He thoroughly agreed with Sir Nathaniel in that. There could be no question that if they adapted armour to the construction of vessels specially for fighting purposes, they could, by combination of armour and cellulose keep water out of shot-holes; and they could produce a vessel which was almost impregnable and unsinkable, provided they went to 14,000 tons to do it. Then they did not get the unhandiness that people talked about. Those vessels were handier than longer steamers. They had the speed, and they would turn more quickly. He thought, with regard to the matter of unarmoured cruisers, they were better off without any, for they were sure to get them into trouble in time of war. If they would develop their own commercial companies, encourage them to build steamers, let them earn their own living in time of peace, and provide them with rapid-firing guns in time of war, they would be more efficient than any unarmoured vessels that they could build.

The PRESIDENT proposed that a vote of thanks be communicated to Sir Nathaniel Barnaby for his paper, which was unanimously agreed to.

The following paper was taken as read:—

THE DEVELOPMENT OF THE MARINE ENGINE, AND THE PROGRESS MADE IN MARINE ENGINEERING DURING THE PAST FIFTEEN YEARS.

By A. E. SEATON, M.I.C.E., M.I.M.E., M. Council, I.N.A.

In this paper it will be my endeavour to trace the development of the marine engine and its appurtenances, and the general progress that has taken place in marine engineering generally during the past fifteen years, rather with the object of attributing much of it to the successful efforts of the members of this Institute in their various capacities, and thereby to render my thanks to them for the very valuable service they have contributed to my profession, than to tell of what has been achieved by the skill, ability, and perseverance of my colleagues in shipbuilding and engineering.

The engineer has been at all times dependent on the ironmaster, and on more than one occasion his progress has been barred by the inability of the latter to overcome some obstacle to success in his manufacture; but, on the other hand, it is equally true that the ironmaster has often been ahead of the engineer, and has been prepared, long beforehand, to supply that which would make a success for the marine engineer if he would avail himself of it. That eminent engineer and most fruitful of inventive geniuses, Trevithick, who a century ago saw instinctively what was possible with steam of high pressure, had to resort to sorry contrivances to try his experiments with the force he knew would be so useful. His boilers, made of copper tubes in granite tube plates, now might serve as a monument to his genius, and as an example of the straits to which he was by the circumstances of his time reduced, rather than as a proof of his ingenuity. It is true that since his day the tube or tubulous boiler has been employed successfully to generate steam of high pressure, and that therefore the boiler in question might be taken as another example of his prescience. It is nevertheless a fact that he did not succeed until the ironmaster of his day gave him iron plates, or, as we should be disposed to call them now, very broad bars. The dilemma that arose as to the shaft of the *Great Western* was removed by the genius of Nasmyth, an engineer; but the steam-hammer without the men to work a forge would have been a useless tool, and the cast iron shaft would have had to take its chance; so that I infer that as much skill and invention were shown by those men who had to manipulate the iron with that hammer for the first time, as was required to conceive, design, and make the hammer itself. History has not therefore been quite fair, for although she has recorded the one feat, and has justly recorded her tribute of praise to the inventor of the tool, so far as I am aware there is neither name nor praise recorded of the men who worked it, nor of the ironmaster who erected it. I do not mean to say that the circumstances are not known, but there are now very few men who could give the information, and although only a comparatively short time has elapsed, their names are practically forgotten.

On the introduction of Siemens steel plates the old Staffordshire list of extras was practically abandoned by steel makers. This had more to do with the progress subsequently made in boiler construction than the introduction of the material of superior strength, inasmuch as it made it possible to construct a boiler with the minimum number of plates at a less expense than one with almost the maximum number. The ironmaster could give us plates nine feet wide twenty or more years ago, but he wanted such a high price for them, that no boiler-maker who worked in competition with his neighbours had the courage to use them, although I am of opinion that it would have paid to do so in all districts where labour was high. And that the boiler-maker did not use them was rather in consequence of his inability or disinclination to reckon the cost. At any rate, he did not employ large plates until they were practically the same price as small ones, and so boilers were constructed in the patchwork form until the era of Siemens-Martin steel. Here, as usual, it was the bugbear of cost that stopped progress, and this same bugbear does to this day often bar our way to the goal that some of us see so far off. You, gentlemen, have often proved yourselves to be our saviours, and we always look to you to remove the obstacles to progress that confront us, as also to the development of new departures. Without your help we would be at a standstill; with it, we can advance step by step; and I am bound to say, in justice to you, that when we make clear our demand for some new thing, you always tackle the problem forthwith, and sooner or later give us what we need. We have not yet, however, exhausted the list of things we want, nor have you yet satisfied all our longings for the things we have asked for. When you give us steel castings without blowholes, steel forgings absolutely free from hair-marks an eighth of an inch below the surface, steel plates that know nothing of the "blue black" state, and that will not give way under any circumstances at a less strain than that to which they have been tested, we will not only be very grateful to you, but will ask for something else that shall give you the enjoyment of exercising your inventive genius, and that splendid patience with which I know you are all endowed.

The period chosen for consideration in this paper is one that embraces the genesis of the modern development of the marine engine and boiler; but it is, moreover, the time that has elapsed since the introduction of Siemens steel, to which I attribute much of the progress that has recently been made. Prior to that time, iron was used almost exclusively in the construction of marine boilers, and very little steel indeed had been used in the engine. Boiler shells were made of Staffordshire iron plates, or of such other iron as was equal to it in both quality and price; the insides, such as the furnaces and fireboxes, were made wholly or nearly so of what was familiarly known as "Lowmoor quality." The price of the latter was very high compared to that of the steel we now use, and may be taken as £30 per ton on the average. The Staffordshire iron would at that time average about £9 for a boiler made of comparatively small plates, and £12 for a boiler made by a more enterprising engineer with larger plates. There was practically no limit to the boiler pressure so far as the internal parts were concerned, but the working pressure was decidedly limited, in so far as it was governed by the shell. There were then some few firms that could supply a plate 1⅛ inch thick of fairly large dimensions, and in some very few instances plates as thick as 1¼ inch were used. Taking the former as the most common and also the most convenient thickness, it meant that a boiler 15 feet diameter would pass only for a working pressure of 75 lbs., or if 100 lbs. pressure was required, the limit to diameter was 11 feet 3 inches for single-ended boilers, and something less for double-ended ones. For a pressure of 150 lbs. the diameter would have been only 7 feet 6 inches. Now, it need not be urged that this was prohibitive of higher pressures, although it had such an effect indirectly, inasmuch as the stays, &c., being of iron, too, would have been either of monstrous size or so close together as to render the construction impracticable. The weight of such boilers was also very much against them, and altogether it required more courage than then existed, and certainly less caution than then obtained, to attempt such strides as have been since successfully accomplished. I have stated that there was no theoretical difficulty with the insides of the boilers, but, as a matter of fact, there were some practical difficulties to encounter. Lowmoor iron was especially liable to blister from innumerable laminations when exposed to heat, and these blisters caused trouble enough with the pressures and temperatures then ruling. What the troubles might have been with the thicker plates, higher pressures, and higher temperatures were not known, and, like all unknown terrors, were feared most. There were also means well known for stiffening the furnace so as to withstand higher pressures; but these very means were also often sources of mischief, and always feared as likely to lead to accidents. It is true that we had the locomotive boiler working at pressures far beyond that of the ordinary marine boiler, but marine engineers were very chary of trusting to it, and events proved that their suspicions were not without foundation; for even now that the locomotive boiler has been used on shipboard to a considerable extent, its success on the sea has been decidedly qualified, and no one will use it unless circumstances compel him, and then only when he can get a supply of fresh water.

The supply of a material possessing all the good qualities of Lowmoor iron, without its bad ones, enabled Mr. Samson Fox, and subsequently others, to weld a cylindrical tube of almost any size, and so manipulate it by corrugating or raising ridges as to render it proof against the pressures we now require. Thus was the internal difficulty got over. That same material had an ultimate tensile strength fully 30 per cent. higher than that of the iron used in the boiler shell, and in addition was of such a nature as to permit of manipulations unknown with that material, and its price is no higher than that of Staffordshire iron. A boiler made wholly of this steel was cheaper, lighter, and better designed and manufactured than one of the older material when of the same dimensions and for the same pressure. Natural conservatism, or some other occult force, seems to have prevented the marine engineer from taking the full advantage of the splendid substitute you gentlemen were prepared to supply him with. I must not forget, however, that there was another force, which is one of the strongest we have in our professional work to combat, that was decidedly opposed to the new material; that was prejudice. I feel even now tempted to take up the cudgels against that old enemy of the engineer, but in this case it would be waste of energy to thrash, as the dog is dead.

So far this was the condition of affairs when fresh demands began to be made on the marine engineer. The shipping world had had demonstrated to it that it was possible to cross the Atlantic at a higher speed than thirteen knots; and that the ships possessing this higher speed did their voyages regularly, and, according to rumour, were paying. Certainly, both the American and the British public showed a preference for them, and there was a growing taste for speed at sea as there had been on land. The Inman and White Star Companies had shown that fifteen knots was not only possible, but could be done with commercial success. But it was urged that to get this speed the ships must be very large, costly in construction, and very expensive in maintenance. This was quite true, and it remained to be seen if they would pay when there were more of them, with the consequent competition. The *Britannic* was built of iron, had iron boilers, and was propelled by ordinary compound engines. She has been a very successful ship in every sense of the word, and holds her own to-day; but her speed is no more than fifteen knots still, and so she has to depend on something besides speed for a character now. She is a ship built prior to my period, and need be no further discussed; she is only taken as one of the causes which made a new demand.

That demand was for more speed. Now, with the same conditions, more speed meant with any ship more indicated horsepower, more coal, larger boilers, and finally, to get the speed economically, finer lines; in other words, less ability to carry the heavier weights entailed by the greater power. The *Arizona* was the first supply to this new demand. Iron was the material used, the compound engine the moving machine. The result was a gain of two knots per hour, equal to 13 per cent., with an increase in coal consumption of 50 per cent.; the carrying capacity for the size of the ship was considerably less, the tonnage under deck being only 5 per cent. more. It will be seen that the cost of this excess of two knots was very great, first in the larger ship, then in the larger engines, then in the increased consumption of fuel; also that, owing to the extra weight of, and space occupied by the machinery, together with the extra coal to be carried in the bunkers, the new ship was less able to earn sufficient freight to meet the expenses of the older ship, and still less able to meet her own. It is therefore evident that such a ship must depend almost entirely on passengers and light goods of high value, to enable her to be run profitably.

In spite of all these serious disadvantages, the demand for such ships continued, so that the *Arizona* was soon followed by the *Oregon* and *Alaska*, still larger and faster ships. These were followed by the *Servia*, *City of Rome*, and *America*. Then came the *Aurania*, *Umbria*, and *Etruria;* and finally we have the *City of New York*, *City of Paris*, *Teutonic*, and *Majestic* of 10,000 tons, and doing twenty knots per hour on the Atlantic regularly. These were the supplies that marine engineers and shipbuilders gave to the demand for more speed. In fifteen years the speed has been increased from thirteen knots to twenty, and there is no reason to doubt that these ships pay very well in spite of their enormous cost and working expenses. Such ships are not only made to pay, but are actually only possible by what has been done by the members of this Institute. Without steel in both ship and machinery, such ships could not be built to accomplish the speed, or to safely withstand the strain of sea and machinery.

The *Britannic* was built of iron, had iron boilers, and her engines were made more or less of iron in one form or the other.

The *City of New York* is built of steel, has steel boilers, and her engines are to a very large extent built of steel. The saving in weight by the use of steel is very considerable in both ship and machinery, which admits of more cargo being carried, or of the lines of the ship being finer, so that a higher speed is possible with the same horse-power, or the same speed with a less horse-power and less consumption of coal.

Having thus briefly sketched out the origin and history of the demand for more speed in the Atlantic service, I will pass from this part of my subject with the observation that if the owners or managers of ships in that trade had been well advised, they would long ago have separated the passenger from the goods trade. A steamer for passenger service only could have been built for the speeds now attained at far less cost in every sense of the word. It is only those who have to work out some of the problems set them by shipowners that appear to know, and to appreciate, the tremendous cost that is paid for the ability to carry the few hundreds of tons of cargo possessed by the "Atlantic Greyhounds."

In 1875 there were many ships in the British Navy capable of doing fifteen knots per hour on trial trips, but very few that could maintain that speed at sea. The necessity of having ships that could maintain that speed existed as soon as the mercantile ships of Great Britain could accomplish it; for not only would it be required that in time of war such ships should be convoyed, but the possibility of an enemy possessing such ships with which to harass the trade of the country was apparent. There was also the necessity for unarmoured cruisers to possess a superior speed to battle-ships for obvious reasons, and to act efficiently as sea-police they must have a speed superior to that of any ordinary ship afloat. Hence the demand for better speed in Her Majesty's Navy.

The competition among the various steamship companies running in connection with railway routes, and others in competition with railway routes, caused a demand for an increase of speed for a different class of ships. In fact, in every direction there existed a demand for more speed, so that there was every incentive to the shipbuilder and engineer to exercise his keenest wit in devising new ways of accomplishing this desirable end.

It will now be my task to show how this has been accomplished by the marine engineer, so that the public can now travel at higher speed, with greater safety, with increased comfort, and at no higher cost, than obtained on the ocean fifteen years ago.

I have stated that one way of obtaining speed was by making ships with finer lines, and this had always to be done at a considerable sacrifice of carrying power. Steel has, however, to a large extent obviated the necessity for such a sacrifice. New methods of construction and new forms of material have also tended to this end. Ironmasters now supply at reasonable rates bars of *Z* section, whereby the framework of the ship is much lighter, and at the same time stronger, than the old combination of angle bars. Then, too, this splendid steel that you now give us is capable of being so flanged, and that, too, when cold, that there no longer exists the necessity of riveting to the plate an angle bar, if it is sought to stiffen it, or to connect it to other work. You supply us now with such materials at practically no extra cost, that we can construct our ships with much fewer plates, whereby we avoid the cost, weight, and disadvantage of so many joints. You are no doubt told from time to time that this new material has a serious fault—that with all its good qualities it is not so durable as the older one. This has a sufficient foundation of truth to make the opposition to it powerful; but with very ordinary precaution and care experience has shown that it can have the same endurance; and there is no doubt that with a better knowledge of how to treat it, this objection will entirely disappear, just as the same objection to iron ships existed, and has now been almost forgotten. The best remedy is to get rid of the mill scale before painting.

But while admitting that the naval architect has done much to bring about a successful solution of the speed problem, I must maintain that the marine engineer has done more. His path was not so obvious nor so clear before him, and new openings have often shown themselves in unexpected places.

Whether the marine engineer starts with a fixed weight given him by the naval architect, or whether the latter accepts such from the former, and designs the ship accordingly, is immaterial. The fact remains that the engineer, in order to get the maximum power, must get each individual horse-power with the minimum of weight, in order that the ship may be a success; and his problem has been how to do this without adopting too costly processes.

His first step in this direction was comparatively obvious. An engine develops so much horse-power at each revolution. If it can be made to do sixty per minute instead of fifty, the gain in power is 20 per cent.; and if the speed was at first 13 knots, it should now be 13·8 knots, or a gain of nearly a knot per hour. But how can we get this increase in the number of revolutions, and is it to be done economically? So far as the engines are concerned, it would mean an increase to the condenser only; and seeing that nearly all steamers at the date in question had too much cooling surface, it would probably have required no increase at all. But we must require more steam for this increase of power; certainly, and so the engineer of that day had to fit larger boilers to his ship. With large ocean steamers this was always possible, but for the smaller steamer it was not always possible, neither was it possible for the small steamer to carry the extra fuel. It is not necessary here to go into details, but it is a fact that the insuperable difficulty with this class in the endeavour to obtain more speed was the impossibility of obtaining sufficient space for the necessary boilers. Some other engineer would, however, attempt the increased number of revolutions by using steam of much higher pressure, trusting to its superior efficiency for the paucity of supply. If his engines were able to digest, so to speak, this superior article, and to make full use of its superior efficiency, he was undoubtedly on the right track. Hence the success of the *Arizona* and the ships that followed her was due to these simple departures. Later your steel admitted of still higher pressures being obtained from the boilers of succeeding ships, and the three-cylinder ordinary compound engines admitted of a higher rate of expansion without any practical drawbacks, as would have been the case with the four-cylinder compound engines of the *Britannic*. The possibility of constructing boilers for higher pressures by the introduction of Siemens-Martin steel, and that such boilers cost less money than the old iron ones, tempted some engineers to use steam at a pressure of 110 lbs. in the ordinary two-cylinder compound engine, but with disappointing results. I am aware that this experiment of ten or twelve years ago has been again tried, and that its new foster-parents state that the system gives as good results as the triple expansion system. They deceive only themselves, and the evidence they give, so far as I have heard it, is conclusive of only one thing, and that is that the new boilers and better arrangement of cylinders that they have adopted now give better results than those they followed formerly. I was quite prepared to hear that the substitution of two cylinders for four, and the use of steam at 150 lbs. pressure expanding ten times would give better results than steam of 60 pounds expanded only six times; this is really what has been proved, and no more.

Having accomplished so much as I have stated, it remained for the engineer to follow the path on which he had found so much success, and we soon found him running even these large engines at eighty revolutions. Taking, as before, the increased power as proportional, viz., 60 per cent., the speed should now be 15·25 knots instead of 13. Revolutions have now done for him as much as he thinks prudent, so he has to start in a new direction, and this time it is in the nature of an enlargement of the engines. His brother engineer of the Naval Board has had to do this long ago, because he had started with a much higher number of revolutions, —in fact, the mercantile engineer is taking up what the naval had left off. The naval engineer, however, is circumscribed in a way not unknown to the mercantile; he can only increase the size of the engine by an increase in the number of the cylinders, or in the diameter of them. He has tried the former since 1867, and until the compound engines forced themselves on him, Maudsley's three-cylinder engines had given him satisfaction, qualified, it is true, owing to a troublesome valve gearing. The mercantile engineer, filled with gratitude for what speed of piston had done for him, now sees his way to getting a still higher speed by lengthening the stroke, so that in 1886 he is getting close to the thousand feet per minute, with engines whose topmost part is visible from the deck without craning the neck through the skylight. Steam is supplied to the monster by numerous huge steel boilers, and the ship can carry little more than her fuel supply for the single voyage.

But before this climax has been reached, a veteran engineer has turned once more to an old idea of his own. His first experiment with it had, through no fault of it or him, failed. He finds that with this new good steel he can now build a boiler of a type well known and tried, and thereby get steam of the pressure he requires with certainty and safety; and in 1881 Dr. Kirk astonishes the shipping world by the success of the *Aberdeen*, having similar engines to the *Propontis*, made by him in 1874, but which failed. And why were the owners of ships so interested in the success of the *Aberdeen*, and what after all was her success? The steam pressure in her was very little higher than some others were then using, being only 125 lbs., and at that time coal was as cheap as it had ever been; so that, although economy in its use was and always is of importance, it was not so much so as to cause a revolution so sudden and complete as that which followed. The fact is, here was the real solution of the speed question.

Since, then, we have all learnt that the triple engine burns less coal, can be run at a higher speed, and has less bulky boilers to supply it with steam than the old compounds, and that was what we were all wanting to obtain, higher speed in every class of ship, even in the so-called ocean tramps, which now glory in a ten-knot speed, whereas formerly the skipper was a proud man who could maintain a level eight knots throughout the voyage. The success, however, of the *Aberdeen* was something more even than this; here was a ship of moderate size, good speed, and good carrying capacity, that was going to do a very long voyage by a route where the coaling stations were far apart, and at some of them the coal very dear. Shipowners could now see before them fresh fields for enterprise, and the sailing shipowner learnt before long that this same Dr. Kirk had created poachers on the realm so long held by him. The sailing ship has not been driven off the high seas, but steamers now run on tracks unknown to them till the triple engine existed.

The failure, in 1874, of the *Propontis* was therefore due to the want of a suitable material for boiler-making, which by 1881 you gentlemen had supplied to us, and permitted such a success to her designer that the trade of the world has been thereby revolutionised. The saving of fuel has been stated, challenged, debated, and discussed *ad nauseam*. The fact remains that it is substantial, and is approximately 20 per cent. where all other conditions are the same. Experience has proved that the three-crank engine is capable of being run at higher speeds than the two-crank one, and that its wear and tear is absolutely less. The boilers being required to supply 20 per cent. less steam, can, of course, be 20 per cent. less; or the same size of boiler will supply steam for 20 per cent. more power. This latter fact was the one made more use of by the generality of shipowners, partly by design, but oftener by unbelief. Hence the superior speed of many of the "tramps" is due to the latter; that of small passenger steamers almost wholly to the former.

On the whole, the saving of coal by means of the triple compound engine has been rather in the direction of the allowance per horse-power than per ton carried, as the ton carried is almost universally carried now at a higher speed. The actual saving is nevertheless a very substantial one, both to the world and to the individual shipowner, for a ship, if run at a higher speed, makes more voyages in a year, so that the trade is done with less capital, which means less tonnage. The demand for less tonnage no doubt depresses the freight rates, and so the unfortunate shipowner does not reap the harvest, but only as it is shared by the public at large. The continued depression in shipping is undoubtedly due to Dr. Kirk's genius, and hence he gets so little praise.

Mr. Thorneycroft,* now so well known as the designer and builder of steam-launches, and, later, of torpedo-boats, soon had to give up non-condensing engines and condense the steam so as to get fresh water for feeding the locomotive boilers he used. The loss of means of draught in the escape steam caused him to substitute artificial sources of air supply, and he found that by forcing air under the grates he could get an increase of steam supply over that given formerly by the steam-blast. The pressure of air was increased from the half inch to as much as six inches of water, corresponding to that of the fiercest draught of an express locomotive; the supply of steam was excellent, and the speed obtained with a steam-launch of considerable size and torpedo-boats larger still was very high, and was at the time considered marvellous. The means whereby these improved results were got were in themselves simple and inexpensive. The compartment containing the boilers was made air-tight, and into it was forced a supply of air from the deck by means of one or more fans of the ordinary type, driven by an independent engine. The simplicity of these means, and the success attending the experiments, led our naval engineers in 1880 to adopt them on a large scale in some cruisers of the *Leander* class, the result being that with precisely the same engines and boilers, and with only the addition of the forced draught arrangement, a considerable increase of speed was achieved. Since that date, similar forced draught arrangements have been fitted to all the new ships built for the British navy, and the example thus set has been followed by the engineers of other countries.

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* I have given Mr. Thorneycroft the credit of the modern application of forced or artificial draught, but the fact is that the first attempt in this direction was made by Ericson in 1828 to the steamer *Victory*, commanded by Sir John Ross, and, strange to say, he enters in his log that "the boiler still continued to leak, although we had put dung and potatoes in it, as directed by the engineers."

As an illustration of what can be done in this way, it is sufficient to instance the case of the first-class belted cruisers of the *Immortalité* class. When working under natural draught, the power to be indicated was 5500 horses, and on the trial trip as much as 6000 horse-power was developed. With forced draught, due to an air pressure equal to two inches of water, it was expected that 8500 horses would be developed by the engines; but, as a matter of fact, on the trial trip and under these conditions over 9000 horse-power was obtained, and the speed was raised from 16½ knots to 19 knots. At the present time, speeds of 20 knots per hour are being realised in Her Majesty's Navy with engines and boilers of such a size as ten years ago would have been deemed sufficient for a speed of only fifteen knots. It is, however, I regret to say, a fact that now very considerable difficulty is being experienced by those having to do with machinery for the English Navy in running continuously under forced draught without more or less trouble with the boilers. This is not, in my opinion, due to the system, but to the want of suitable provision in the boiler design for the conditions under which they have to work when being pressed to the utmost. It is, in fact, a little error of judgment on the part of the authorities into which they have been led by the perfect success of their previous efforts in the same direction; and just as the locomotive engineer of to-day is dependent on, and has the utmost faith in, the forced draught by which he gets express speeds, so the marine engineer will get over his difficulties as the locomotive engineer did, so that in the near future we shall see ships whose boilers are worked under forced draught with perfect safety and confidence doing express speeds.

In the days of natural draught and compound engines, 10 horse-power per square foot of grate was thought to be a good output; with the introduction of the triple engine and higher pressures a natural draught would give 14 to 15 horse-power per square foot of grate; and the modern forced draught now in use in large ships enables us to get 20 horse-power per square foot of grate; and in smaller boats, where the air-pressure in the stokeholes has been raised above two inches, even higher results have been reached.

With the success of the principle of forced draught came the usual number of enterprising inventors with their inventions, some of them good, some of them not worthy of notice, but all of them more or less misunderstood so far as the objects aimed at and the end to be attained were concerned. As a means to a particular end, forced draught has been a success; as a means to the several ends had in view by experimenters, it has not been a success. When the consumption of a larger amount of fuel per square foot of grate with a consequent increase in the supply of steam was the object, no one could complain; but that there should be an economy of fuel per horse-power was not to be expected, although it is true that with some kinds of coal, and in some kinds of boilers, the more rapid combustion, and the more intense heat obtained, have been attended with a slight economy in consumption. It is claimed by certain inventors that by their patents economy is effected, inasmuch as the air forced into the furnaces is to some extent heated by the waste gases in the uptake and funnel; but seeing how low the specific heat of air is and the short time to which it is exposed to the heating process, it is very doubtful if the gain would outweigh some of the disadvantages of the system; and, on the whole, I am inclined to think that our Admiralty system of closed stokeholes is the best, and that economy must be sought in the better firing that is possible under these conditions than to the heating of the air supply—not that I by any means undervalue the advantage of the regenerative process.

Where forced draught has been used in the mercantile marine for speed purposes, I hear of little or no complaint, but when introduced for the sole purpose of effecting economy of fuel, the praise is of a very qualified nature, and the complaints, when made, are unmistakable.

To sum up, the three great *developments* of marine engineering that have been made in the past ten years are—

1st. Increase in working pressure from an average of 75 lbs. to an average of 150 lbs. per square inch.

2nd. The adoption of the triple and quadruple expansion system, so as to utilise steam of this high pressure efficiently.

3rd. The adoption of artificial means for obtaining sufficient draught for the consumption of coal, and, when desired, for an increased consumption of coal so as to give an augmented supply of steam without additional boiler capacity; with the result that in naval ships now with practically the same weight of machinery, the indicated horse-power is nearly doubled, and, in the mercantile marine, the indicated horse-power is 50 to 75 per cent. more for the same weight of machinery as was used fifteen years ago, the consumption of coal being 20 per cent. less than ten years ago, and 25 to 30 per cent. less than fifteen years ago.

I now come to the *progress* that has been made by the marine engineer in the design and manufacture of machinery, whereby the engine of to-day, notwithstanding that it is lighter and even cheaper than that of fifteen years ago, is worked with less wear and tear and fewer accidents. Although, from the tremendous demand made for sea-going engineers (so that the supply has not been all that could be desired), the marine machinery of to-day is probably not in the hands of such experienced and skilful men as then, it does not suffer thereby, while at the end of twelve months' work it is in better order now than was the case fifteen years ago. I do not wish by any means to disparage the skill and ability of our sea-going engineers, but I think that I shall be supported when I say that younger faces are to be seen in the engine-rooms to-day taking important positions there than was the case fifteen years ago; that whereas then a natural taste and aptitude for the profession was a *sine quâ non* for entrance into it, it is now flooded to a great extent by young men who simply look on it as being more lucrative than some other professions and trades to which admittance is easy have now become.

That constant complaint of hot bearings is practically become a thing of the past is partly due to improved construction and better design, consequent on a better understanding of first principles; but good white metal has done almost more, as it has been found to be a panacea for the evil where it has existed for years in the older engines; and whereas formerly it was only warships and those of the best mailship companies that indulged in the luxury of white metal, now the meanest of steamships has, as a rule, this metal in the main bearings, and crank-pin brasses, as a matter of economy; for a hot bearing always means an expensive bearing, both in coal consumption, and in wear and tear and renewals. The increased length of life of crank-shafts is due to the absence of hot bearings, as well as to the lighter strains put upon them. It is white metal that has permitted of the high number of revolutions per minute that I have already pointed out as being one of the conditions of high speed in ships.

I would also express the opinion that the crank-shaft of to-day is better made and of better material than was the case fifteen years ago. Improved methods of manufacture of iron forgings, and the improved steel which you, gentlemen, give us, admit of a better surface, and the well-made and heavy lathes of the present day can do the work not only cheaper but truer than was the case then. It is to be hoped that the combination of the crank-shaft makers in England, whereby the price is kept up, will act in maintaining the quality, and, if possible, raising it beyond what it was when competition was so severe.

In the construction of the modern marine engine the most marked feature of change is the quantity of steel castings introduced, sometimes in the place of forgings, sometimes in the place of iron castings, and sometimes in the place of brass castings. I ventured more than twenty years ago, when I was a student of engineering, to predict that the time would come when we should get steel cast into the various forms we required, and that, with the introduction of such a metal, cast iron would gradually disappear from the marine engine. My prophecy has been fulfilled in a sense sooner than I anticipated, but cast iron has not yet been driven from the field so rapidly as might have been expected after the introduction of steel castings. The fact is, that you, gentlemen, have not yet learned the full secret of success; and I do not say this reproachfully, for so many of your members have worked energetically at the problem and have improved in your productions in such a comparatively short time, that you deserve praise rather than censure. We engineers do complain—sometimes very savagely—of the delays we experience in obtaining steel castings, and of the loss to us when, after machining for days, we open up such faulty places as to necessitate the condemnation of the castings; but in our calmer moments we are fain to admit that our wonder should rather be, not that bad castings are made, but that we sometimes get good ones. Ten years ago my firm commenced using steel castings in lieu of iron ones, for such parts as were subject to shock, and were of so plain a design as to be easily cast. We then substituted cast steel for forgings, the strain per square inch on which was very light. For these purposes all we required was a material whose ultimate strength was at least twenty tons, and which, before breaking, would stretch at least 5 per cent. At that time, our particular sources of supply were Messrs. W. Jessop & Sons, Limited, Sheffield, and Mr. Aesthöwer of Annen (Germany). The German castings were very sound, and came up to the standard laid down, but went very little beyond it; while those of Messrs. Jessop & Sons were only fairly sound, but they possessed a tensile strength of thirty tons, with an elongation of 20 per cent., and in some cases they were even better than this. With these latter we ventured to go further than we had done before, and we made of them some of the smaller working parts, which were subject to higher strains, and eventually the connecting-rods for two engines of considerable size. These rods have now been running for seven years without showing signs of failure. Messrs. Jessop have made crank-shafts of large size of this material, even, I believe, to 15 inches diameter, with most satisfactory results, and the castings, when machined, were free from blowholes, draw-cracks, and even sponginess, while they had all the appearance, when finished, of having been forged. The pieces cut from these castings when tested were found to have as high a tensile strength and as good an elongation as a steel forging, so that, from *primâ facie* considerations, such a shaft was equal to a forged one, and I am not aware that experience has proved the contrary. To-day we are constructing in the works of my firm (Earle's Shipbuilding and Engineering Co., Ltd., Hull, England) engines of 12,000 horse-power, in which the foundations, the whole of the columns, the pistons, the thrust-blocks and collars, the eccentric straps, the cylinder and valve-box covers, and many other of the minor details, are made of cast steel. The saving of weight is such, that, taking *one* of these engines—they are twin screws—and half the boilers, that is to say, taking a set of machinery of 6000 horse-power, its weight is 560 tons, against 900 tons, the weight of a set of engines, boilers, &c., of 6000 horse-power made in 1870, and 1000 tons that of compound engines in 1875, and which at that time were deemed to be the lightest of the kind, and were run at very nearly the same number of revolutions as the modern one. The ship for which our engines are intended is being built by us, and has a cast steel stem, a cast steel stern-post, a cast steel rudder, and cast steel propeller brackets, besides other cast steel fittings for gun and other purposes throughout the vessel. The fact is that our demand for steel castings is now large, and is, moreover, a progressive one; and when you, gentlemen, by means of aluminium, nickel, or any other "doctor," will give us sound castings that we can rely upon, so that we may not throw away our money by machining, only to discover defects by which the castings are condemned, we will prove even better customers than we are now.

In 1875, Messrs. Vickers, Sons, & Co., of Sheffield, were making very large crank-shafts and other shafts; and in the Atlantic it was getting to be the custom, when a shaft broke, to substitute one of Vickers' for it. They were, however, a very expensive luxury; and as the wrought iron shaft generally gave its owners timely warning of when it was going to break, and the steel one didn't, the latter was treated as untrustworthy, and was not adopted by the majority of engineers or shipowners. To-day, instead of there being only one firm that can make these shafts, we have a dozen, and at least half a dozen of these whose reputation stands in the first rank. The Siemens furnace now produces steel for shaft purposes at as low a rate as ruled for the Bessemer in 1875. The substitution of hydraulic presses for steam-hammers, too, has not only improved the quality of these forgings, but most undoubtedly has been the means of reducing their price, and we now have steel crank-shafts, steel propeller shafts, steel piston and connecting rods—in fact, every forging of steel in a warship and in the highest class of mail-steamers, and throughout the mercantile marine there is a general tendency to substitute this superior metal for the inferior. In H.B.M. Navy the shafting is made in accordance with the plan introduced by myself in 1872, whereby, by making the shafts hollow, a considerable reduction is effected in weight, with an exceedingly small reduction in strength. For example, a shaft 10¼ inches external diameter, with a hole 5 inches diameter through it, is equal in strength to a solid 10 inch one, but its weight is only a little over three-fourths that of the solid one. I need hardly say, however, that the difference in cost is considerable; in fact, there is the added cost of boring out the hole. Siemens steel is now very little dearer than ordinary crown quality iron, and no dearer than the best qualities of iron required by marine engineers, so that all the bolts, studs, nuts, and pins used by my firm are of steel.

The general effect of the substitution of steel for iron in the construction of a marine engine is to save weight, and at the same time to have a stronger machine. The modulus of elasticity being with steel only about the same as that of iron, renders it impossible to make any very substantial decrease in scantlings of many of the parts, but generally such a decrease is effected, and so the modern engine, composed almost entirely of steel, is lighter than one of iron. The collapse in the *City of Paris* (s.s.) has no doubt shaken the minds of some as to the use of steel castings; but I think it has been proved most conclusively at the trial that the accident was not in any way due to the steel castings, and that they did give way is perhaps not to be wondered at under the circumstances. At the same time, I am of opinion that it is unwise, with our present knowledge of the trade, to cast columns hollow, *i.e.*, cored throughout their length. It is, of course, possible to do this successfully, but the risk of it is great, and the liability to obscure cracks and unseen faults must be also great.

At all events, my experience with the material has taught me to avoid such a form as far as possible, and certainly never to make an important part like a column of an engine a hollow casting, more especially with a thin section.

I do not suppose it is of equal interest to your Institute, but it is nevertheless a fact that very marked improvements have been made in the manufacture of bronze castings and also of bronze forgings. Fifteen years ago a gun-metal casting, with an ultimate strength of fifteen tons per square inch, and an elongation of 5 per cent., was considered very satisfactory; but to-day we have the various bronzes, such as phosphor bronze, manganese bronze, Stone's bronze, aluminium bronze, &c. &c., having strengths varying from twenty to thirty tons per square inch, and in some instances even a higher ultimate tensile strength than thirty tons, with an elongation approaching that of steel. Forgings made from some of these metals have proved to be equal to steel in strength, and the cost of these bronzes is very little beyond that of gun-metal. Advantage has been taken of this by the marine engineer to use forgings of these metals in lieu of brass castings, drawn bars in lieu of either brass castings or iron forgings cased with brass, and, finally, to make propeller blades of it instead of cast iron, steel, or even gun-metal. I will not detail here the gains in speed attributed to the substitution of the bronzes for steel or iron, but content myself with accepting as a fact, and stating the same to you, that propeller blades being made of thinner sections, having keener edges and a smoother skin, give a better result than the heavy cast iron blades did, or than the steel can possibly do when pitted and roughened by sea-water. The action of sea-water on these bronzes is sometimes capricious, but generally only slight. The English Admiralty, acting upon their own experience, have discarded the use of all the bronzes except phosphor bronze and ordinary bronze or gun-metal (consisting of 87 per cent. of copper, 8 per cent. of tin, and 5 per cent. of spelter). So far this distrust of other bronzes is not shared by the mercantile marine. I have, however, seen some remarkable failures with certain of the bronzes. For example, a new propeller fresh from the makers was found, after lying on a wharf for a few weeks subjected to severe frost, to be cracked so seriously as to be utterly useless. It is also a thing not unknown to the mercantile marine to lose one or more propeller blades without notice; and as indicative of the direction in which engineering opinion may be tending, the latest thing in propeller blades we hear of is a bronze casting with a cast steel core, or perhaps you, gentlemen, would prefer to say a steel casting with a bronze skin.

The progress in propeller design and construction has been very slight, although each month seems to produce a new inventor with a new propeller—at least new to the inventor—that is going to revolutionise the shipping world; but in spite of newspaper paragraphs full of hope and promise, if, alas! somewhat showing great want of scientific and technical knowledge of the first principles of propulsion, the screw propeller remains without a rival. Its shape has not altered much, although the very bad forms have gradually died out; and although much has been claimed for those having the pitch varying in all kinds of ways, the fact remains that in the Navy, as in the mercantile marine, those who have given most thought to the subject and most observation, prefer a propeller of uniform pitch throughout—in other words, it is desired that its acting surface shall be part of a true helix.

Propulsion by twin screws has many practical advantages, but it is chiefly now adopted from considerations of safety, inasmuch as a ship with two screws is less liable to have both injured at the same time, and therefore her whole propelling apparatus broken down, than one with the single screw; and in case of accident to the steering gear, she can be steered by varying the revolutions of the engines. Moreover, a smaller propeller is required for each of the twin screw engines than that needed for a single engine of same power; hence in the case of a deep draught ship, owing to the deep immersion, the twin screws work with a higher efficiency, and in the case of a shallow draught vessel the same holds good, inasmuch as they are thoroughly immersed when the single screw of the same power would be partly out of the water.

The adoption of steel boilers naturally suggested the advisability of using fresh water, not so much on grounds of cleanliness as of avoiding corrosion. This bugbear, however, has proved, like many others, not to exist. Experience has shown that the steel boiler does not corrode any more rapidly than the iron one; and, as a matter of fact, the life of boilers made of steel is likely to be very considerably longer than that of iron ones. The first steel boilers made by my firm twelve years ago are working at their original pressure, under the inspection of the British Board of Trade and Lloyds, and they are likely to continue to do so for many years yet to come. I am, of course, aware, and would remind you, that this increase of length of life is due in no small degree to the better treatment accorded to them. The use of zinc in the form of cast slabs or rolled sheets, especially in the earlier months of their life, has been the means of preserving boilers in a way not known before; and the general practice of causing the feed water to enter the boiler at a comparatively high temperature has also tended to increase their durability; but I repeat that under the same conditions the steel boiler shows no tendency to corrode any faster than the iron one, and the steel boiler has, besides, the advantage over the iron one of not developing blisters in the internal parts exposed to flame, so that the patching of furnaces is a comparatively rare thing now-a-days.

The demand for fresh water for feed purposes has been emphasised since the use of steam of 150 lbs. pressure and upwards, especially for vessels making long voyages. It goes without saying that the power to generate steam in any boiler must decrease very quickly as the scale on the heating surface increases, and also that the temperature necessary to produce steam of a certain pressure gets higher as the density of the water increases; hence, when the waste is made up with sea-water in boilers whose working pressure is 150 lbs. and upwards, the speed of the ship decreases towards the end of the voyage, and, what is worse, the boilers often give out, and require extensive and costly repairs. The consumption of coal is also very much higher than it would be if the boilers were kept clean throughout. Attempts to remedy this evil were first made by carrying a supply of fresh water in the double bottoms of the ships or in tanks specially provided for the same. This expedient helped matters, but was not a perfect success, as the water supply often contained large quantities of sulphate and carbonate of lime, which formed a hard scale, and which, together with the sea-water, made a worse scale than the sea-water itself—that is, worse to deal with afterwards. This water also cost money, and, what was more objectionable, the carrying of it often reduced the quantity of cargo. Other attempts were made to supply fresh feed to the boilers by means of the donkey-boiler, the steam from it being condensed in the condenser and pumped into the main boilers. The donkey-boiler, however, became then a sufferer. As a rule, they are not easily cleaned, so that it was only a matter of time for this source of supply to fail, and to be not available for some days. Finally, Mr. James Weir, of Glasgow, whose inventions, especially for improving the efficiency of the boiler, are of wide repute, introduced his now well-known evaporators, which consist really of a small horizontal boiler, ingeniously contrived so as to be easily taken to pieces and cleaned, and the water in it evaporated by the steam from the main boilers passing through a set of tubes placed in its bottom. The steam generated in this boiler is admitted to the low pressure valve-box, so that there is no loss of energy, and the water condensed in it is, of course, returned to the main boilers. The extra supply from it is still obtained at the expense of coal, but without any risk of injury, and at a more economical rate than was the case when a donkey-boiler was employed. Other engineers have designed and patented apparatuses to do the same work, and it is now getting to be a universal practice for all ocean-going steamers to have feed evaporators. Mr. Weir's feed-heater, whereby the feed water, before entering the boiler, is heated up very nearly to boiling-point by means of the waste water and steam from the low-pressure valve-box of a compound engine, is another most useful appliance, and was introduced in 1878; it is also becoming every day more and more used, and, in conjunction with Mr. Weir's special feed pumps, is a very desirable thing to have in every steamship, as not only is the feed water delivered to the boiler warm, but so regularly, and with such very slight risk of cessation, as to render the engineer on watch quite easy on the score of feed supply.

It is claimed for many feed-heaters that they are the means of effecting an economy ranging as high as 15 per cent. I mean marine feed-heaters, where the heating is done by steam, and not by waste gases in the uptake. It is not obvious how there can be any saving at all, and in my opinion the tens and fifteens per cent. are apocryphal. That steam is better maintained in the boilers with such appliances is undoubted, and that in cases where difficulty has been experienced in keeping up the full pressure, the fitting of a feed-heater has been the means of doing it; so that there must be some saving, although in the nature of "robbing Peter to pay Paul." The fact is, the warm feed assists rather than retards the circulation, and the saving is more in that direction than in any other.

Improvements have been made in the engine-room and boiler-room of nearly every steamer in the direction of making the work lighter both at sea and in port, and the occupation of the engineer not so severe. Ventilation has been better understood and practised. The covering of the hot parts by non-conducting material has been extended, and the substitution of superior non-conductors, such as fossil meal and asbestos compositions, has unquestionably effected a saving. Steam starting gears, too, have during the last fifteen years been introduced into all classes of ships, and even the smallest of them now may be found provided with this appliance for the more rapid handling of the engines. Steam turning gears and steam ash hoists have been also introduced, and all such fittings must naturally tend to the more economical working of the vessel.

In conclusion, I would beg to summarise by saying that in fifteen years the speed of steamships carrying passengers has been increased from 30 to 40 per cent.; the consumption of coal per horse-power has been decreased from 20 to 30 per cent., or say an average of 25 per cent.; the cost of a horse-power has been decreased by almost a similar amount, and in some cases is but a half of what it was in 1875; and the safety, comfort, and convenience of the travelling public has been enhanced instead of sacrificed. These successes are largely due to the members of the Iron and Steel Institute, and the balance is due to the skill and ability of marine engineers, but it must not be forgotten that the whole has been backed by the enterprise and sagacity of the shipowners.

FRIDAY, OCTOBER 10TH.

Mr. **ALEXANDER THIELEN** (of the Verein Deutscher Eisenhüttenleute) occupied the chair at the commencement of the proceedings, followed by Mr. H. M. **HOWE** (Vice-President of the American Institute of Mining Engineers), in the absence of the Hon. **ABRAM** S. **HEWITT**, President of that Society.

The **CHAIRMAN** said, that, by the courtesy of their American friends, he was called upon to preside on the second day of their International Congress at Pittsburgh. Before proceeding to the formal business of the day, it was his pleasant duty to convey the most sincere thanks of the Society he represented to the American Institute of Mining Engineers, who had invited them to come over and take part in the discussion of papers, and who had given them an opportunity to see the vigorous iron and steel industry of that great and rising country. The Verein Deutscher Eisenhüttenleute had accepted their cordial invitation with the greatest pleasure; but they had not anticipated that the numbers who crossed the Atlantic would have been so numerous. The forty or fifty whom the most sanguine of their Council had expected to come over, they were ashamed to say, had risen to the number of 142, who had enjoyed the privilege of being the guests of that and of kindred societies—in fact, the guests of the whole nation. The hearty welcome they had received took away from them the feeling of being strangers in a land where they felt that the difference in tongue was the only partition between them. When they left the shores of the Fatherland, they were not pleasure-seekers. They wanted to make use of all their facilities, and to gain instruction and knowledge. They went to view and gain instruction by visiting the splendid works, in all the various branches of the iron and steel industry, which they had seen and would see, and which showed that in America they were not only able to give the best records in respect of quantities, but that they possessed many clever engineering and mechanical devices a long way ahead of anything they had seen in their home-works in Germany. The riches which a kind Nature had bestowed upon America were not neglected, but were turned to the most practical use, and they believed that the progress made by the United States within the last twenty years, in the history of the iron and steel trade, would be very far surpassed by the progress they would make in the next two decades. The liberality with which they had thrown open many of their works; the great willingness they had shown in answering many embarrassing questions; the heartiness of their reception; the princely style of their hospitality; and last, but not least, the luxurious way in which they were to pass through over three thousand miles of America, would never be forgotten by the Verein Deutscher Eisenhüttenleute. Should any of their members come to the old Fatherland, they guaranteed him or her that they would find the same hearty reception on the part of the members of the German iron and steel trade, even if they could not compete with the brilliant preparations which the different committees had made for their reception in the United States. He regretted that Mr. Hewitt was prevented from taking the chair, but the eloquent words spoken on the 1st October by Mr. Andrew Carnegie, and on the previous day by Dr. Ricketson, had touched their hearts, and had made them feel as friends of the iron and steel trades of the United States. He wished also to extend their sincere thanks to the President and Council of the distinguished Iron and Steel Institute, who had, in the most liberal manner, invited all the members of the Verein Deutscher Eisenhüttenleute to take part in their meeting in New York.

Dr. R. W. Raymond said that nearly twenty years ago, when the American Institute of Mining Engineers was founded, the first names which it placed on its list of honorary membership were the names of Sir Lowthian Bell—then plain Lowthian Bell, but not less dear to them on that account—and Peter Ritter von Tunner, who in 1840 had established what was now the Mining Academy of Metallurgy of Leoben in Styria, and to whom more than to any other man—he might safely say more than to all other men—it was due that that school had become the central seat of the science of metallurgy of iron in the world. He did not ignore the distinguished services or the brilliant careers of instructors and investigators in other countries. He did not forget Grüner in France, Åkerman of Sweden, and the brilliant Chersy

—too early a loss—at Fribourg. He did not forget the laborious researches of Percy and of Bell; nay, it was on the authority of such distinguished men that he rested his assertion of the fame of Peter von Tunner. It was by the universal and unanimous acclaim of such men that they recognised Peter von Tunner as the Nestor of their profession.

The Iron and Steel Institute and the Verein Deutscher Eisenhüttenleute had both set their seal upon that verdict of the experts, by electing, as the American Institute of Mining Engineers had done, to their honorary membership Professor Tunner, who therefore stood connected with that assemblage by a triple bond, he being an honorary member of every one of the three Societies there represented. It was a most fortunate and significant coincidence, that that day upon which they were gathered there, in that amicable International Conference, was the day when, across the sea in Leoben, the school which Tunner founded celebrated its fiftieth anniversary, and a few hours from that moment another honorary member of the Institute of Mining Engineers, Professor Hoefer of Leoben, would be delivering in that distant mountain-pass the jubilee oration in honour of Tunner and of Tunner's school. He had been honoured by the privilege conferred upon him of making a motion that that meeting send a cable despatch to Professor Hoefer, something that he could—he was going to say put in his pipe and smoke—put in his address and speak it when he addressed the congregation that would be assembled in celebration of that happy anniversary. He wished only to say that he accepted the honour for the sole reason that the one man of their American Society who should take that place was disqualified by illness from being present to do so. He referred to their past President, Dr. Sterry Hunt, who, thirty-five years ago, was the colleague of Tunner at Paris, and subsequently, on several occasions his co-labourer—one of the few men in their young Institute whose scientific career ran back as far as Tunner's, and who should have spoken to that resolution. Without further remark, he would read a brief letter from Professor Hunt, who wrote from the chamber of illness—he hoped he might say the chamber of convalescence—in New York city, and who therefore, he hoped, might be accepted through his letter as speaking in his own person.

"*October* 1, 1890.

"DEAR DR. RAYMOND,—The mention of the name of Peter von Tunner, of Leoben, awakens in me pleasant and tender memories. More than thirty-five years since, at the great Exposition at Paris in 1855, I was the youngest of a group of jurors appointed to examine and judge the objects therein belonging to the domain of geology, mining, and metallurgy. It is sufficient to mention among my colleagues the names of Elie de Blaumont, Dubronsy, De Chancourtois, Callon, De Vaux, Warrington W. Smith, and Peter von Tunner. Of that group of jurors, so far as I am aware, Von Tunner and myself are to-day the only survivors. How he endeared himself to me, and to us all, by his assiduity, his earnestness, his simplicity, and his profound knowledge of the principles and details of his profession, I still remember with delight. Again, in 1876, having as colleagues our honoured fellow-members Sir Lowthian Bell and the lamented Alexander Holley, whose monument in bronze we have so lately unveiled in New York, I was a judge at our Centennial Exhibition at Philadelphia. It was then my good fortune, at one of the informal evening gatherings of our Institute of Mining Engineers, to receive as our guest the Ritter von Tunner, and to bid him welcome to the Institute, which he had already honoured by his membership. I well remember his pleasant surprise and his emotion at this greeting, after twenty-one years, from his former colleague. And now in the fulness of time are gathered the representatives of three Societies, one from Great Britain, one from Germany, and a third, their friendly rival, all devoted to that profession which Von Tunner has done so much to render illustrious, and each claiming him as an honorary member. And by a happy coincidence they meet in the great centre of the American iron industry on the day when Leoben celebrates the jubilee of its world-famed metallurgical school, and of its founder, Peter von Tunner. What more fitting and proper than that we should send across the sea on this occasion our hearty greetings? I therefore venture to propose a telegraphic message from our International session conveying our congratulations to Von Tunner and to Leoben.—Yours truly, T. STERRY HUNT."

The CHAIRMAN said he had the honour to move that a cable despatch be sent to Professor Hoefer, the orator of the day at Leoben, conveying the congratulations of that meeting to Ritter von Tunner and the Leoben Academy in the following words:—"The International Session of German, British, and American Engineers and Metallurgists send greeting to Tunner and Leoben."

Sir LOWTHIAN BELL said his friend Professor Raymond had wisely abstained from entering into any details with regard to the eminent services which had been rendered by his friend Ritter von Tunner to the science of metallurgy. He had done so simply because to enumerate them would be to traverse almost the entire field of scientific investigation in respect to the metallurgy of iron. He had very great pleasure indeed in seconding the resolution, because in the first place his acquaintance with Ritter von Tunner was probably longer than that of any of the gentlemen whom he had the honour of addressing. He had the pleasure of making the acquaintance of Professor von Tunner fifty years ago exactly, just about the time that his friend was engaged in founding the college at Leoben. Circumstances prevented him from availing himself of the advantage he might have derived from an acquaintance with so illustrious a man as the Professor, but some eighteen or twenty years after that, he had the pleasure and the advantage of reading the researches the Professor had made on the action of the blast furnace, and it was only when he came to fully appreciate the value of his services that his own mind was directed to a further inquiry into the actions of that most important instrument in the manufacture of iron. Since that time they had kept up a frequent correspondence, and in fact he could not overrate the bonds which had united them when he said, that a more affectionate and more valued friend he never possessed in his life. Every letter he received from him was replete with expressions of the kindest character. He (Sir Lowthian) had forgotten at the time when the Mining Engineers of the United States honoured the Professor and themselves by electing him as an honorary member that he himself owed a debt of gratitude to his American friends for a similar distinction, which he prized the more from the fact of receiving it at the same time that it was conferred on Ritter von Tunner. He should not trespass further upon the time of the meeting, because the work they had to do was considerable. He should therefore now content himself with seconding, which he did in the most cordial manner, the proposition just submitted to the meeting by his friend Dr. Raymond.

Professor G. LUNGE, of Zurich, in supporting the motion, said, that after the eloquent words of Professor Raymond, it only remained for him to express his great pleasure on being able to support the motion, especially as Ritter von Tunner was one of his countrymen. They had heard yesterday from Sir James Kitson of the great number of English engineers who had developed the iron industry, and it was a great pleasure to him to have one of his own countrymen upheld as having contributed in a scientific way to the development of the great industry with which they were all connected.

The resolution was then submitted to the meeting, and carried unanimously.

The CHAIRMAN said he was glad to be able to submit a further resolution, namely, "That a message be sent from this meeting in memory of those gentlemen who have left us—Mr. Grüner, Mr. Holley, Dr. Percy, Sir Wm. Siemens, Mr. Thomas, Mr. Adamson, Dr. Grass, and Mr. Paul Kupelweiser, stating that this meeting holds fresh in its memory the good work which they have accomplished."

Mr. GILCHRIST, in seconding the resolution, said he wished to tender to Sir James Kitson his hearty thanks for permitting him to second Herr Thielen's proposition. The name of Grüner would be revered by metallurgists for all time, for in his writings they found great truths clearly expressed. As an example of this, he had only to remind them that Grüner's writings, so long ago as 1856, clearly stated why phosphorus was not removed in the Bessemer and Siemens furnaces. Dr. Percy, their grand old English metallurgist, was one of the first, if not *the* first, to codify their metallurgical knowledge. Alexander L. Holley, their great steel engineer, was one who, by his visits to European steel-works, and by his remarkable power of seeing where mechanical improvements were required, had a large share, if not the largest share, in enabling their cousins, the Americans, to beat them in the output from steel plant of the same furnace capacity, and that, too, without any sacrifice of quality. Sir William Siemens was one of the most versatile inventors the world has ever seen, and, amongst his many achievements, would always be remembered by the open-hearth or Siemens-Martin process for making steel, and by his regenerative furnace. Sidney Gilchrist Thomas, without having read the writings of Grüner or the blue book of Snelus, independently discovered how steel could be produced in the Bessemer and Siemens furnaces from phosphoric pig, and, in conjunction with his cousin, worked out the commercial part of the process, aided by many friends, such as Edward P. Martin, E. Windsor Richards, Henri Schneider, Joseph Massenez, R. Pink, Arthur Cooper, Edward Riley, Gustav Pastor, Paul Kupelwieser, and the Acieries d'Angleur, and also, in conjunction with his cousin, watched over and extended the use of the process then known as the basic or Thomas-Gilchrist process. Finally, Daniel Adamson, one of the pioneers in the use of steel for boilers, like Holley, did much to promote, and had dear at heart, the visit they were paying their cousins across the ocean.

The motion was carried unanimously, and a telegraphic message was at once forwarded to England in accordance therewith.

An abstract of the following paper was then presented by the author :—

THE PROGRESS OF GERMAN PRACTICE IN THE METALLURGY OF IRON AND STEEL SINCE 1876.

WITH SPECIAL REFERENCE TO THE BASIC PROCESSES.

BY DR. HERMANN WEDDING, BERLIN, GERMANY.

INTRODUCTION.

IT is now fourteen years since we German ironmasters, in considerable number, visited the United States on the occasion of the Philadelphia Exposition, and found the iron metallurgy of this country, as must be frankly confessed, in an advanced stage of development not previously suspected by us. At that time the United States already occupied, as now, the second rank, with Germany in the third, the product of pig iron for that year being, in Great Britain 6550, in this country 2093, and in Germany 1850 kilotons.* This relative position has not been changed. The present annual product of the three countries is, in round numbers, Great Britain 8380, the United States 7790, and Germany 4530 kilotons. But the proportion of the United States, which was, in 1876, but 15 per cent. of the world's product, has now advanced to 30 per cent.

When we left America in 1876, it was not only with gratitude for cordial hospitality, and for the liberality with which our professional colleagues here had opened to our inspection whatever was worthy of notice in our special field, but also with the conviction that we had collected a great treasure of new and interesting information which we could utilise for the benefit of our German Fatherland. In particular, the achievements of the never-to-be-forgotten Holley in the field of Bessemer practice set us an inspiring example for imitation in our own country.

As an expression of our thanks in more practical fashion, I attempt in this paper to sketch what we have done in Germany since that time in the metallurgy of iron and steel, venturing to hope that some portion of what I bring forward may prove useful to our American brethren.

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* The kiloton is 1,000,000 kilogrammes, or very nearly 1000 tons avoirdupois, the metric ton of 1000 kilos weighing 2204·6 lbs. avoirdupois.

Germany (including Luxemburg, which is included in the Customs-Union with the Empire) produced in 1876 and 1889:—

		1876. Kilotons.	1889. Kilotons.
Iron ore		4,712	11,001
Coal and lignite		49,550	84,892
Pig iron		1,846	4,525
Castings		436	940
Malleable iron	Ingot iron	249	2,046
	Weld iron	943	1,655

I use the words ingot iron (*Flusseisen*) and weld iron (*Schweisseisen*), which are employed by us in official documents, and in the Custom-House, and the first of which practically comprises all that is called "steel." It is not my purpose to urge again the international harmony of nomenclature which was planned in 1876, but, unfortunately, not completely achieved. I would only remark that we Germans get along very comfortably with the names then proposed, which we adopted at once.

The figures given above may serve to prove that we have taken some pains to maintain our position as the third nation in the competition of the iron-producing world.

I. ORES AND FUELS.

Like the United States, and unlike England, France, and Belgium, Germany is fortunate in possessing within its own borders the raw materials for its iron industry. There is an importation of ores from Spain, Sweden, and Hungary, it is true, but it is not strictly necessary, and, in fact, is more than offset by the exportation of German ores. In other words, we mine considerably more than enough ore for all the iron we make. Since 1876, indeed, the centre of gravity of the German iron ore production has moved. It now lies in Lorraine and Luxemburg, on the western edge of the Empire, where 57 per cent. of our ore-product is mined.

We possess very few ores that are free from phosphorus, and those which we have are so manganiferous that they cannot, generally speaking, be used to make pig iron for the acid Bessemer process. On the other hand, we have an abundance of phosphoric ores, the greater part being so rich in phosphorus as to be suitable for the manufacture of pig for the basic Bessemer or Thomas process. The remainder is composed of ores of medium tenor in phosphorus, and suited only to the manufacture of forge and foundry irons.

So far as the acid Bessemer practice is still maintained among us, it requires foreign ores; and this need is supplied chiefly from Spain.

The proportion among the different classes of ores in the product mined is about as follows:—

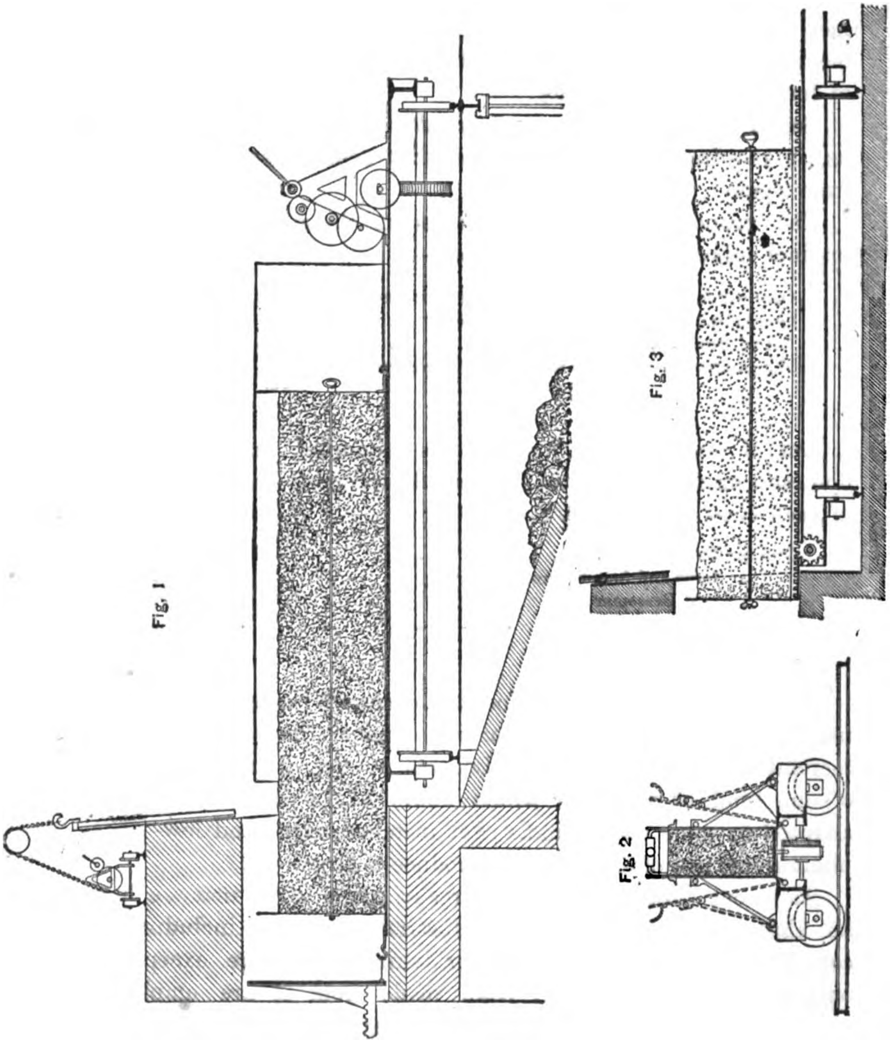
Ores which can be used by themselves to make Thomas pig	64·6
Ores suitable for forge and foundry irons	22·2
"Acid Bessemer" ores	2·8
Manganiferous ores (used to make white pig and spiegel)	10·4
	100·0

But if we add the foreign ores imported, and deduct the domestic ores exported, we have as the proportional consumption of each class in Germany:—

Ores for Thomas pig	52
" " forge and foundry irons	22
" " acid Bessemer pig	15
" " spiegel, &c.	11
	100

This statement, however, does not correctly represent the actual use of the different classes; for it frequently happens that commercial conditions make it advisable to use, in the production of one kind of pig, ores which would be, of themselves, better adapted to some other kind. For instance, high- and low- phosphorus ores are often mixed to produce a forge-iron.

As to our fuels, the figures already given show that we have an abundant supply for all industrial purposes, including, of course, the iron manufacture, for which, with rare exceptions, only bituminous coal and coke made from it are employed. Moreover, our coalfields will not be exhausted in many centuries. Unfortunately, not all our coal-basins furnish the material for coke suitable for the blast-furnace. Strictly speaking, there is but one basin—the Westphalian or Ruhr coal-basin—which satisfies this condition to the satisfaction of the ironmaster. In other districts—as, for instance, that of the Saar—coke is indeed made, but of greatly inferior quality as compared with the Westphalian. In Upper Silesia, the coke made with the greatest pains from domestic coals would seem, nevertheless, to a stranger an utterly impracticable element in the regular conduct of a



Quaglio's Apparatus for Charging Stamped Coal into Coke-Ovens.

blast-furnace. This difficulty has caused in Germany, perhaps more than in any other country, the careful testing of all means of improvement, and the adoption of those which stood the test, in order that the quality of the coke made from poor coal might be made serviceable.

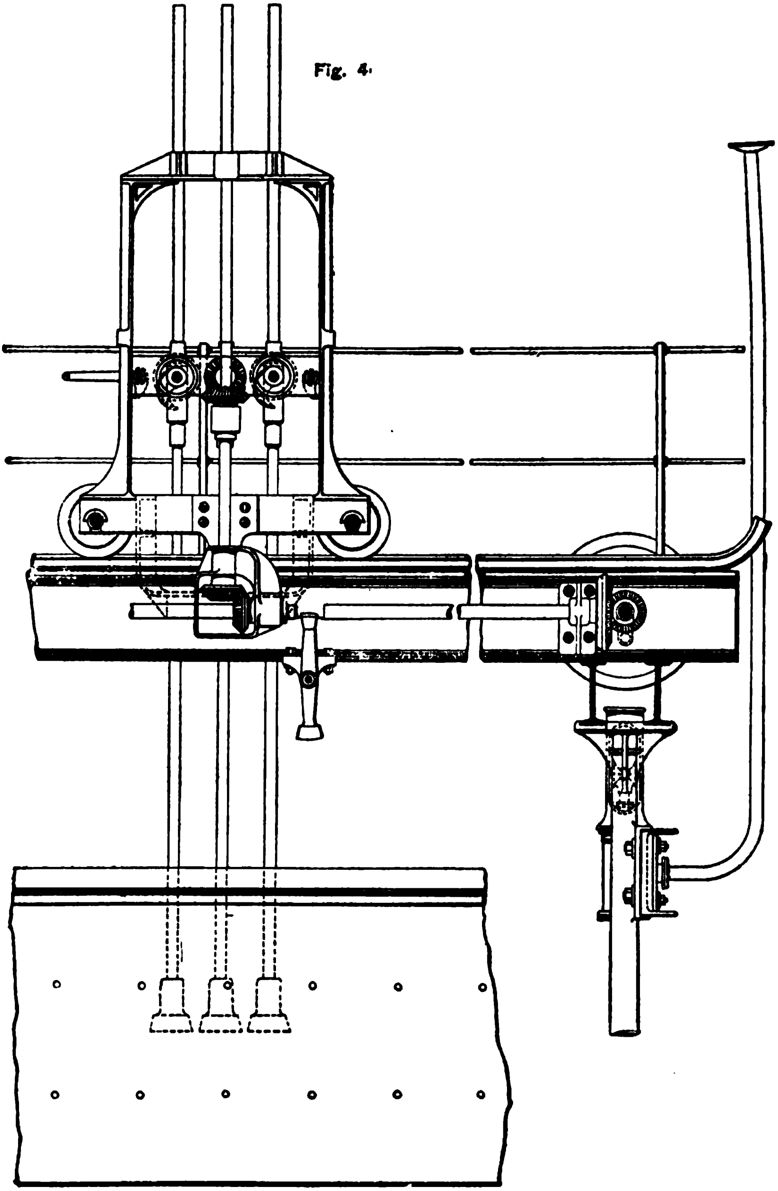
Dr. Otto estimates the coke-production of Germany at 26,313 kilotons, of which 13,401 should be credited to the Ruhr basin, 4168 to Upper Silesia, and 2092 to the basin of the Saar.

The difficulty with German coking coals is usually to be found, not so much in an excess of ash, as in the lack of "coking quality," even when the ash is low. So far as the ash is concerned, an adequate remedy has been found in careful washing after sizing. Our coal-washing apparatus leaves little to be desired, now that the principle of a preliminary sizing has been fully recognised.

But, as already observed, some of our coals—especially, for instance, those of Upper Silesia—have already so small a percentage of ash, that washing will not sensibly reduce it; so that, although the preliminary crushing is performed as an advantageous preparation for the coking process, it is not worth while to proceed to wash the crushed coal.

There is a decided advantage in crushing the coal before coking, in the more intimate contact of particles thus secured. Experience has shown that the smaller the quantity of heavy hydrocarbons in the coal (these being the well-known determinants of its coking quality), the closer must the solid particles be brought together in order to form a cohesive coke. To this end many means have been proposed and tried. The attempt has been made, without practical success, to press the coal together in the coke-oven. Again, the coal has been made into bricks, which, by reason of their regular shape, could be packed tightly together in the oven; but this practice also has failed of general adoption. Finally, resort has been had to the method of stamping the coal in a box, and charging into the oven the whole of the thick slab thus produced. This procedure has given satisfaction at German works, and is now in somewhat extensive use. The apparatus shown in Figs. 1, 2, and 3, from the German patent of J. Quaglio (No. 36,097), is used especially by Upper Silesian coke-makers (Julienhütte and Friedländer), who, however,

Fig. 4.



Quaglio's Travelling Stamper for Fine Coal.

everywhere stamp by hand instead of using a stamping-machine, as shown in Fig. 4.

In proportion to the amount of by-products obtainable by condensation from the gases of coking (which is not always in proportion to the total amount of the gases themselves), is the inducement to include in plants and practice the saving of such by-products. At many works, tar and ammonia (which latter is usually converted at once into sulphate) are separated from the coke-oven gases by condensation. But this is not by any means the last word of progress in this direction. It has been found that, as in gas-distillations, so in the condensation of the coke-oven gases, the proper regulation of pressure and temperature permits the formation of a whole series of useful by-products. This system is now employed to an ever-increasing extent, particularly in Upper Silesia.

The arrangement of such a condensing-works is shown in Figs. 5 to 14, from a communication of Dr. Otto, of Dahlhausen, to the Society of German Ironmasters. The ovens here represented have each a capacity of 5·75 metric tons of dry coal, and the coking requires forty-eight hours. The gases which remain after the condensation consist essentially of light hydrocarbons, and are approximately free from oxygen and nitrogen, especially if the ovens are so well built and maintained that the entrance of atmospheric air into the coking-spaces is completely prevented. These gases are further utilised in heating—primarily the coke-ovens themselves, under the floors and between the walls of which they are conducted. But the gases are, after the condensation is over, so far cooled that they will scarcely ignite spontaneously, and, once ignited, do not continue to burn freely. Hence, either the gases, or the air which is to burn them, or both, must be pre-heated. The practice had been introduced, at one time, of providing regenerators (see Figs. 5, 6, and 7) to be heated by the burned gases (after these, by their combustion, had heated the coke-ovens), and to heat in turn the freshly entering gases and the air for their combustion. But it has been demonstrated, especially by the experiments of the well-known constructer of coke-ovens, Dr. Otto, of Dahlhausen, that this pre-heating of the gases may very well be omitted if the air is sufficiently heated. The resulting oven-construction is

Fig. 6

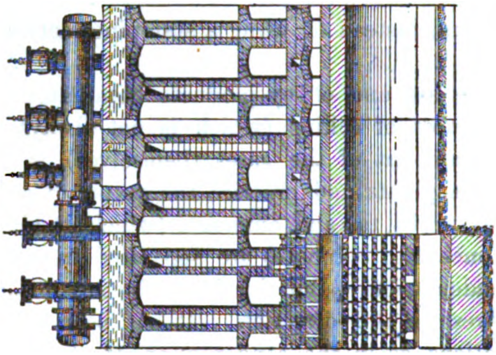


Fig. 5

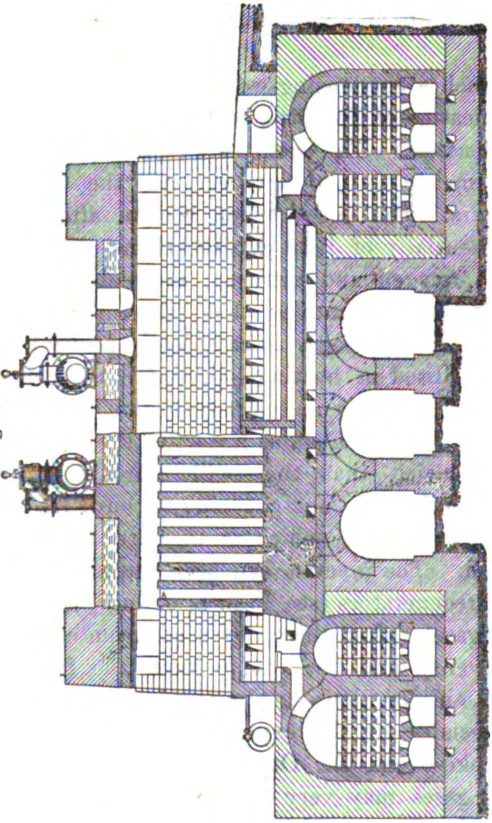
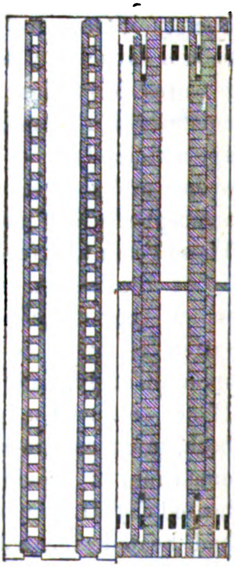


Fig. 7



Regenerative Coke-Ovens at Pluto Mine, Westphalia.

shown in Figs. 8 and 9, while Figs. 10 to 14 give the condensing-works, and Fig. 15 the general plan.

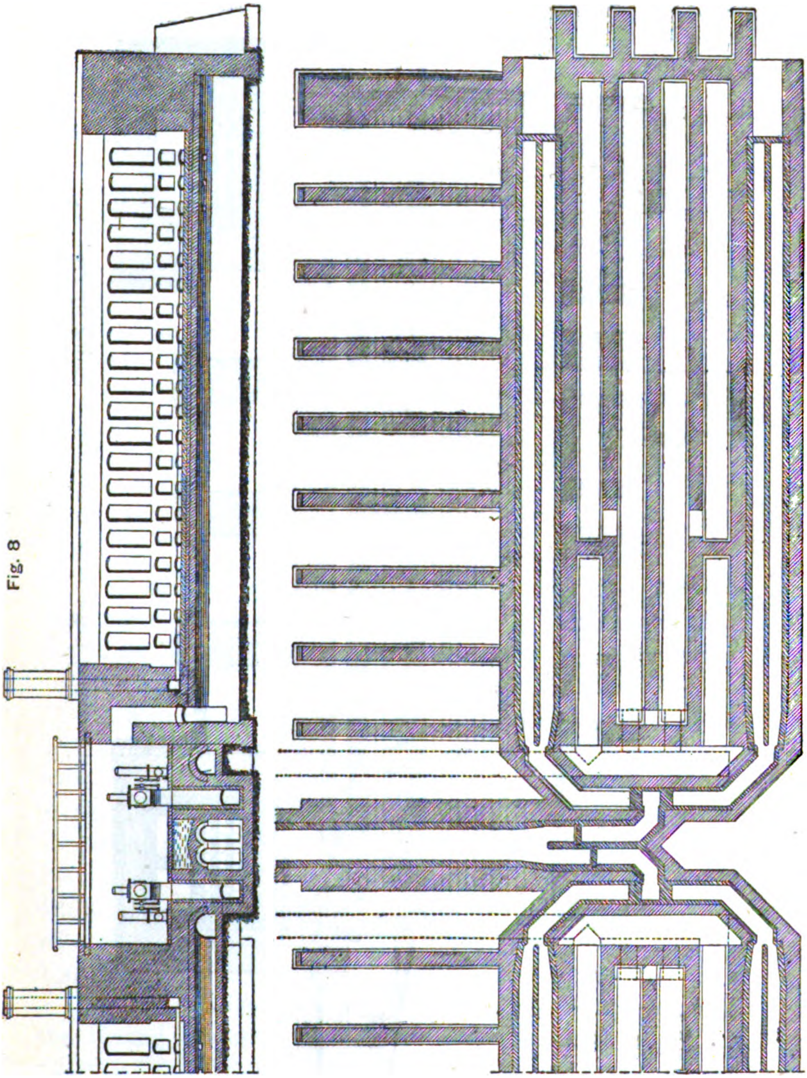


Fig. 8

Section and Plan of a Double-Bench of Coke-Ovens with Condensers.

If the ammonia from the first condensation is too weak, it is enriched on gas-washers until the ammonia-water shows 3° to 3½° Beaumé.

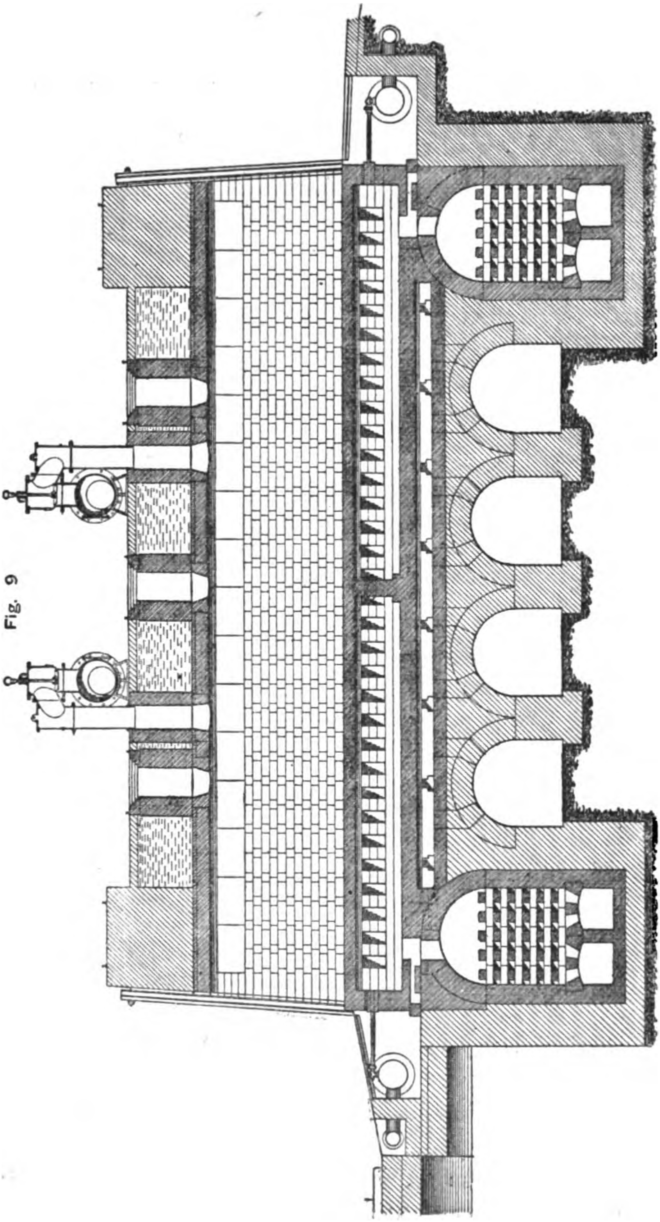


Fig. 9

Longitudinal Section of Regenerative Coke-Oven for Saving By-Products.

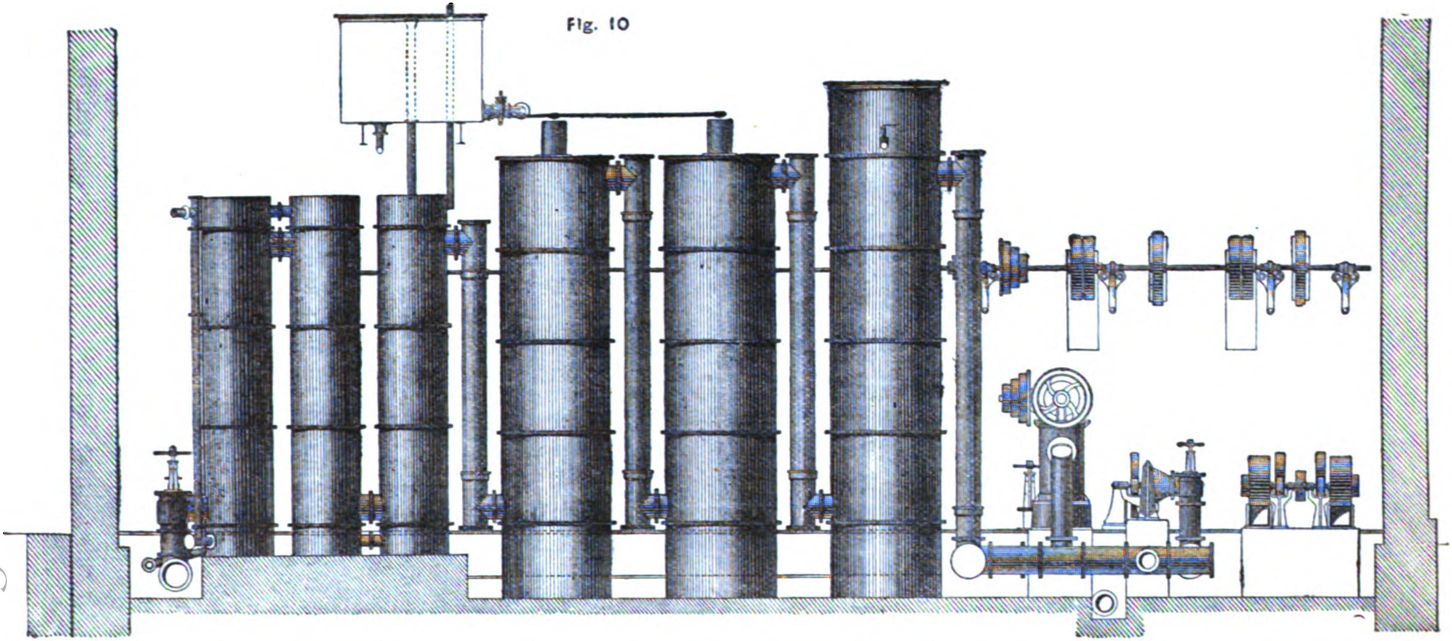
The gases, the temperature of which in the floor-flues of the ovens is 1200° to 1400° C., and in the side-walls 1100° to 1200° C., show, as a rule, at the foot of the heating-flues, over 700° C. still. When they finally escape, therefore, from the flues, they carry so much heat that they have been further used under steam-boilers with other fuels. Often (and especially in Upper Silesia) the quantity of gases is so great that a small part suffices to support the coking, while the rest can be otherwise utilised. Mr. Bremme, an engineer at Julienhütte, has succeeded in finding, after the separation of the gases, a very advantageous use for the latter portion in the heating of blast. The gases, which are free from dust and ashes, and give a high calorific effect, are burned in brick heating stoves (Cowper system). This has furnished a remedy for the difficulty encountered in Upper Silesia by reason of the large amount of zinc-dust in the blast-furnace gases usually employed to heat the hot-blast stoves.

II. BLAST-FURNACE PRACTICE.

The conditions of the German blast-furnace practice vary greatly. The native ores are nowhere nearly so rich as the more important ores employed in America; for instance, the specular ores of Lake Superior, and the magnetites of the north-east. Perhaps there is no other district in the world where the furnace-charge carries so little iron as in Upper Silesia, where it sometimes falls below 30 per cent. It is not merely the low content of iron in the ores, but also its usual accompaniment—a high tenor in silica—which causes this character of charge. Concentration of the ores is, with a few exceptions, commercially impracticable. The finely-divided condition of the ore in the gangue prevents any separation by gravity without a previous fine-crushing; and this, again, would introduce new difficulties into the working of the blast furnace.

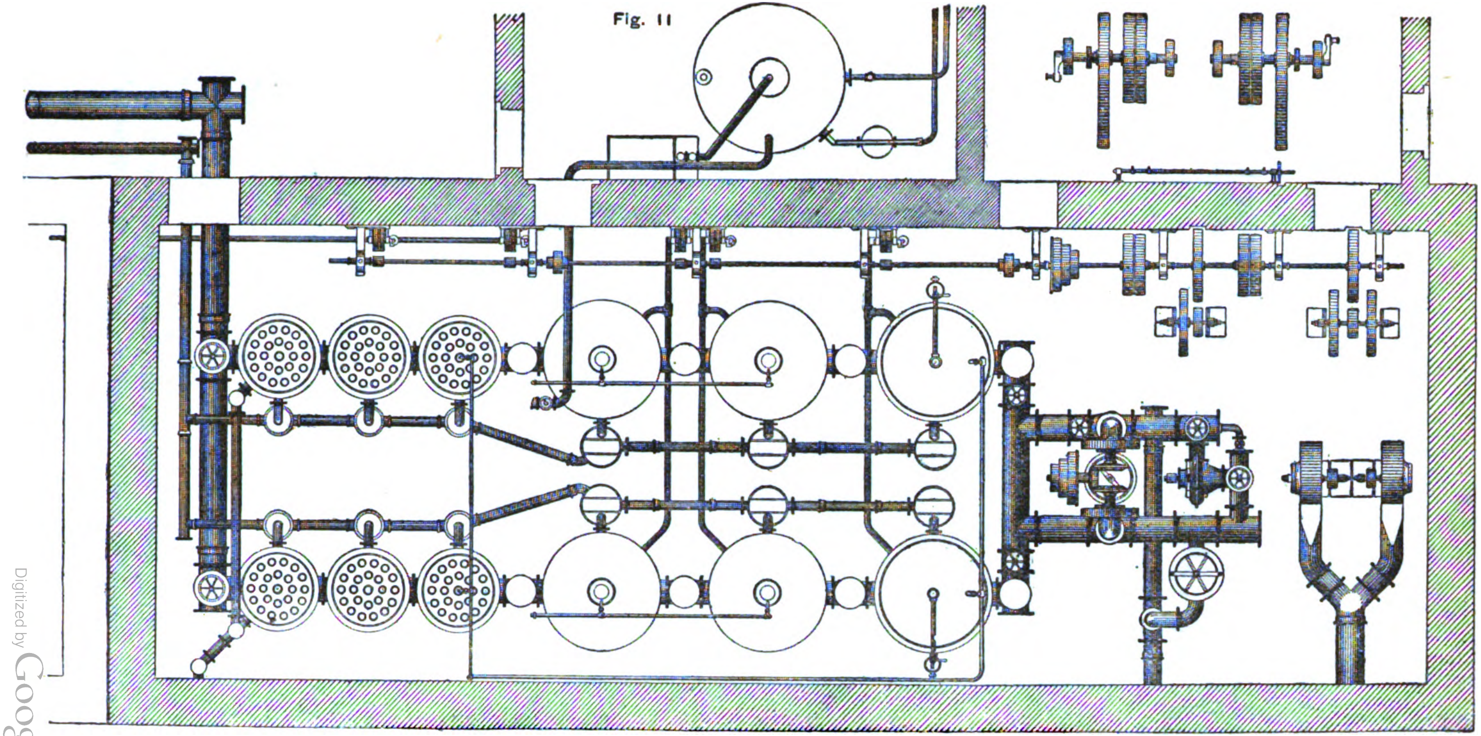
One disadvantage we have in common with the ironmasters of the United States—namely, the necessity, as a general rule, of railway transportation over considerable distances for ores, or coke, or both. But we lack magnificent waterways, like the great lakes of the North; and the development of internal canals, as a remedy for this natural disadvantage, is still delayed in Germany.

Fig. 10



Elevation of Condensing and Purifying Apparatus for By-Products from Coke-Ovens.

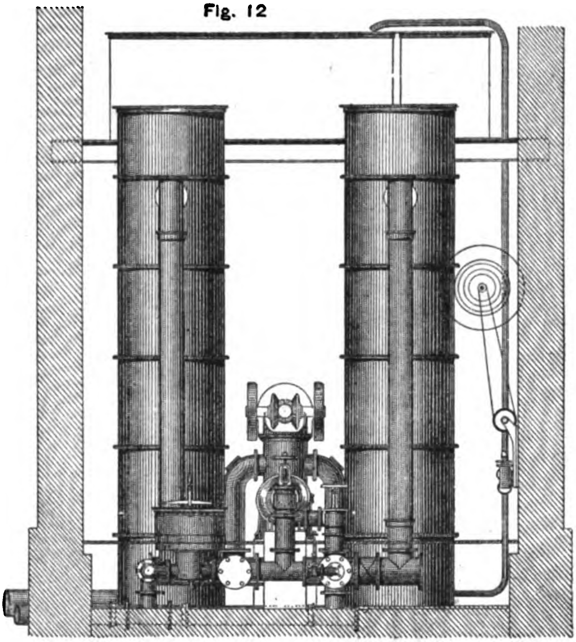
Fig. 11



Plan of Condensing and Purifying Apparatus for By-Products from Coke-Ovens.

To give instances of our transportation of materials: most of the iron ores smelted in Westphalia (where, as already observed, the best coke is made) must be brought from the Siegen district, from the Lahn, and from Lorraine. On the other hand, notwithstanding the abundance of iron ore in Lorraine, the ironmaster there must import not only Westphalian coke, but also (by reason of the sulphurous character of the native ores) manganiferous ores from the Lahn as a mixture. And in all this transportation there is no water-route except a short piece of the Rhine.

Fig. 12



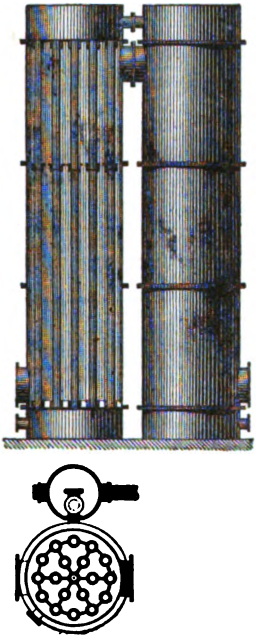
End View of Gas-Washers in Condensing Plant (Figs. 10, 11).

The most favourably located furnaces, with reference to the nearness of the raw materials, are those of Upper Silesia.

In blast-furnace construction, practice inclines more and more to the entirely free stack without exterior masonry (*Rauhgemäuer*). Figs. 16 (Plate XXV.), 17, 18, 19, and 20, from the Friedenshütte in Upper Silesia, and Figs. 21 and 22, from Hörde in Westphalia, show the general proportions and arrangement. Lürmann's cinder-notch is universally used. Generally the furnace is closed in front, as a crucible furnace (Fig. 16). The old-fashioned fore-hearth (*Sumpfofen*) occurs, however, when (in the production of Bessemer or Thomas pig) casts are to be made at brief intervals. But in this case also the cinder-notch is used, since the interspace of the fire-hearth is entirely closed by tamping (see Fig. 23).

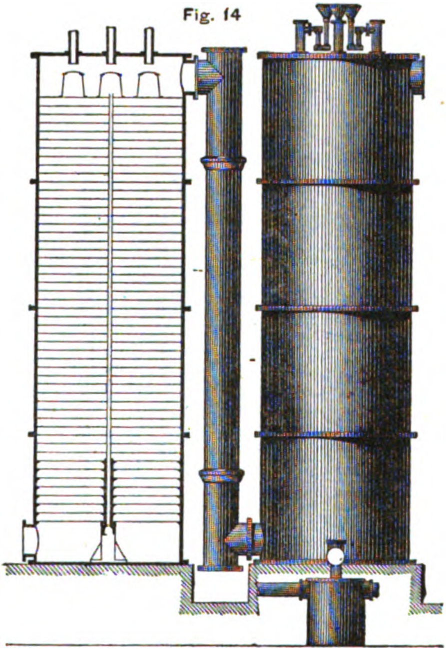
The removal from the furnace-walls of the weight of the tunnel-head, bell, &c., is becoming more and more complete. The closed top (for lump ores, usually the Parry cone, shown in Fig. 24, from Lorraine; for fine ores, the Langen bell-charger, frequently provided also with an interior suspended gaspipe, contracting downwards, as shown in Fig. 21) is always hung from the top platform and carried by special supports, mostly columns of iron pipe. The closed top, with interior suspended pipe, at the Hörde furnaces does not, indeed, satisfy the theoretical principle that the gases

Fig. 13



Section and Elevation
of Gas-Cooler.

Fig. 14

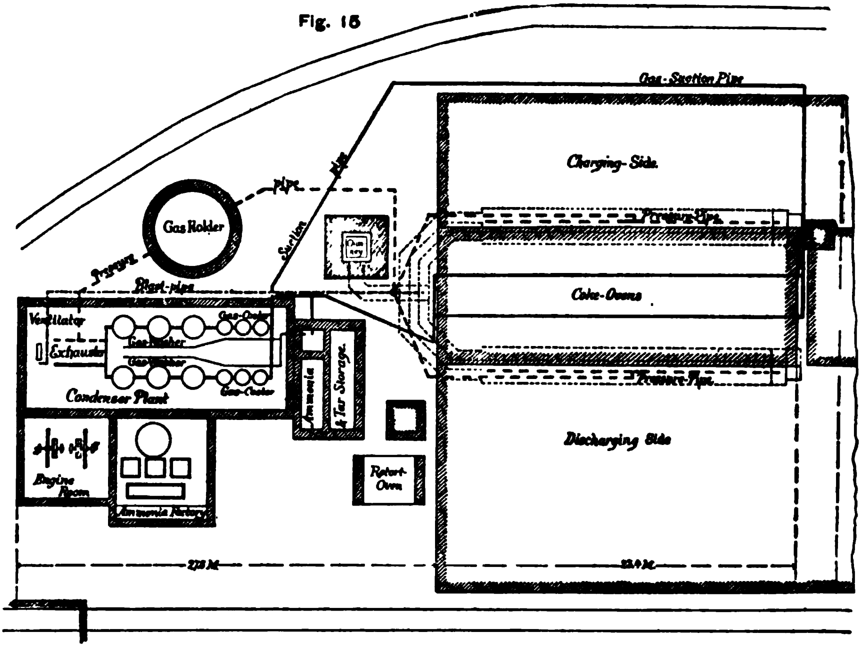


Section and Elevation of
Gas-Washer.

should be collected either only above or only below the stock-level; but it has proved itself the best *charging* apparatus, probably because, by means of the suspended pipe, the centre of the stock-column is most effectively kept loose. At these furnaces the bell is operated by steam.

Lürmann was the first to emphasise the desirability of making the different parts of the blast-furnace more independent of one another than formerly, and of relieving the lower parts from the weight of the upper. Fig. 25 shows such a construction. But some have gone still further and separated the parts of the furnace-walls above the bosh, connecting each by means of a ring and brackets with the supports of the top platform.

Fig. 15



General Plan of Coking- and Condensing-Works at the Pluto Mine, Westphalia.
(Details in Figs. 10 to 14.)

The cooling of the hearth is generally very complete, from the bosh to the bottom. Yet it seems to have been rendered partly or wholly unnecessary by an arrangement which has been devised by Director Burgers at Gelsenkirchen, namely, the employment of carbon bricks made of retort graphite or of coke-dust (con-

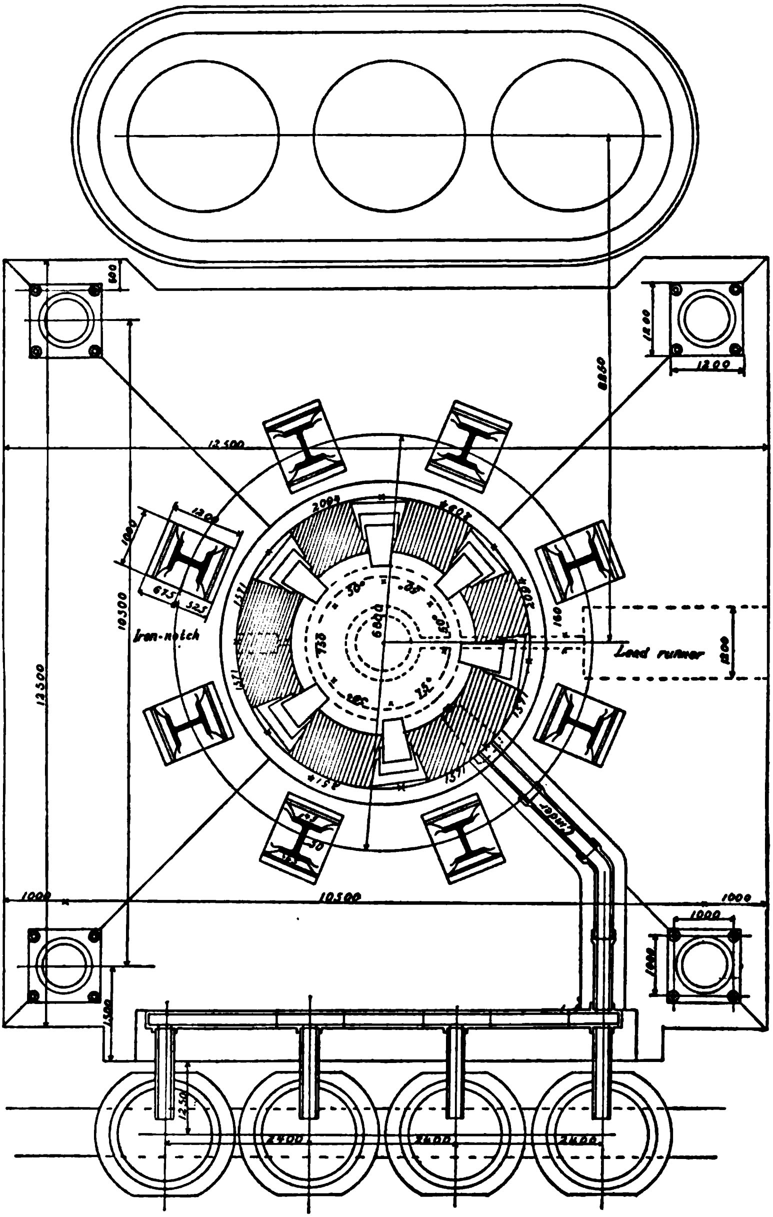
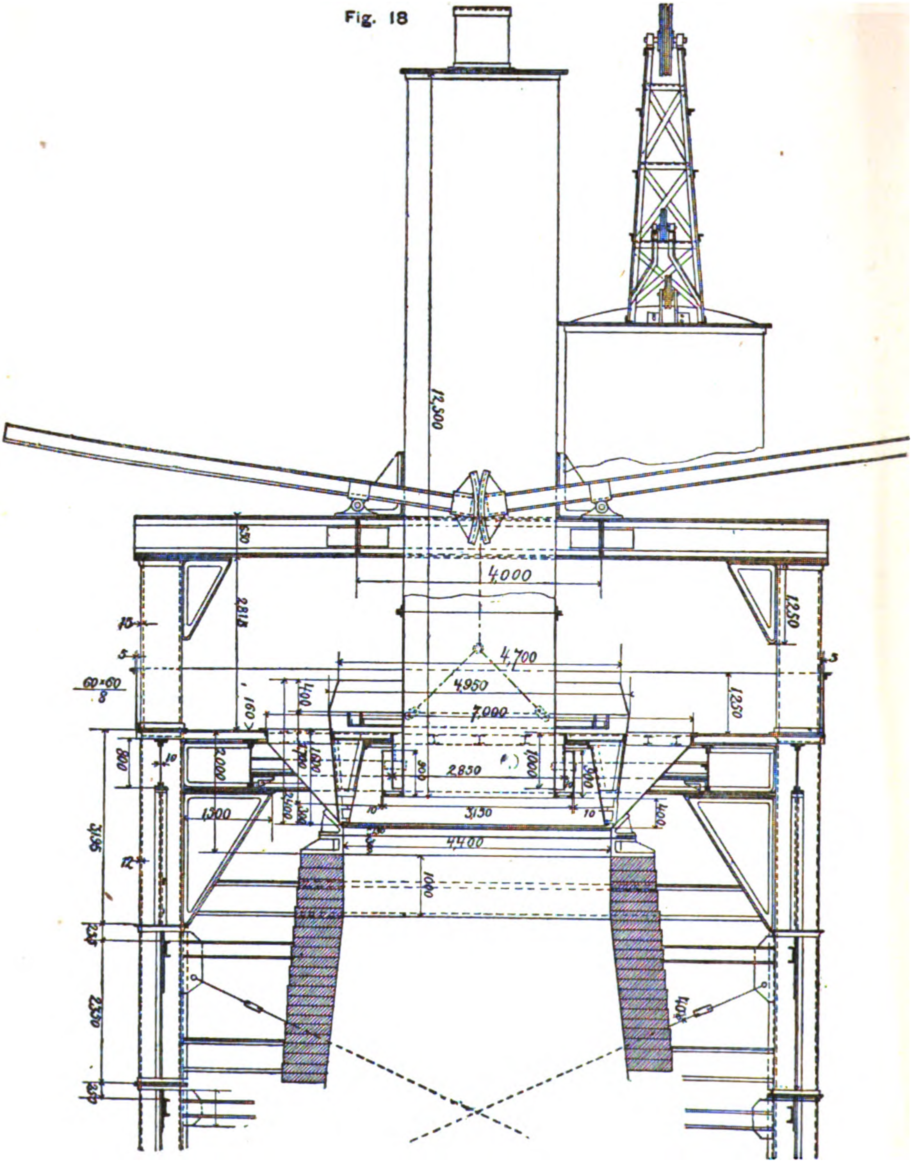


Fig. 17

Plan of No. 1 Blast-Furnace at Friedenshütte, Upper Silesia.

taining 1 to 2 per cent. of ash), moulded with tar and glow-

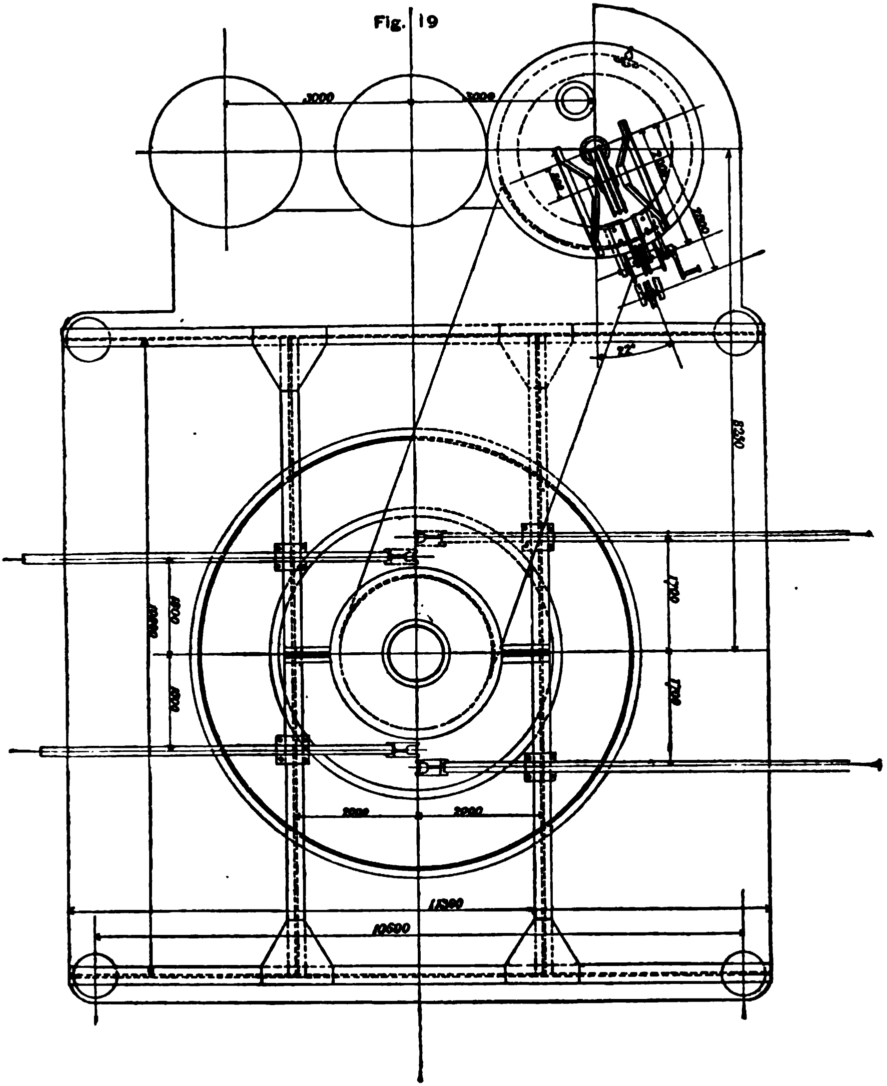
Fig. 18



Vertical Section of Closed Top and Charger of No. 1 Blast-Furnace at Friedenshütte.

heated (*aeglüht*). These are substituted for the ordinary fire-bricks of the hearth, and seem to be well adapted even for the bosh- and belly-walls. They are likely to find increasing use

Fig. 19

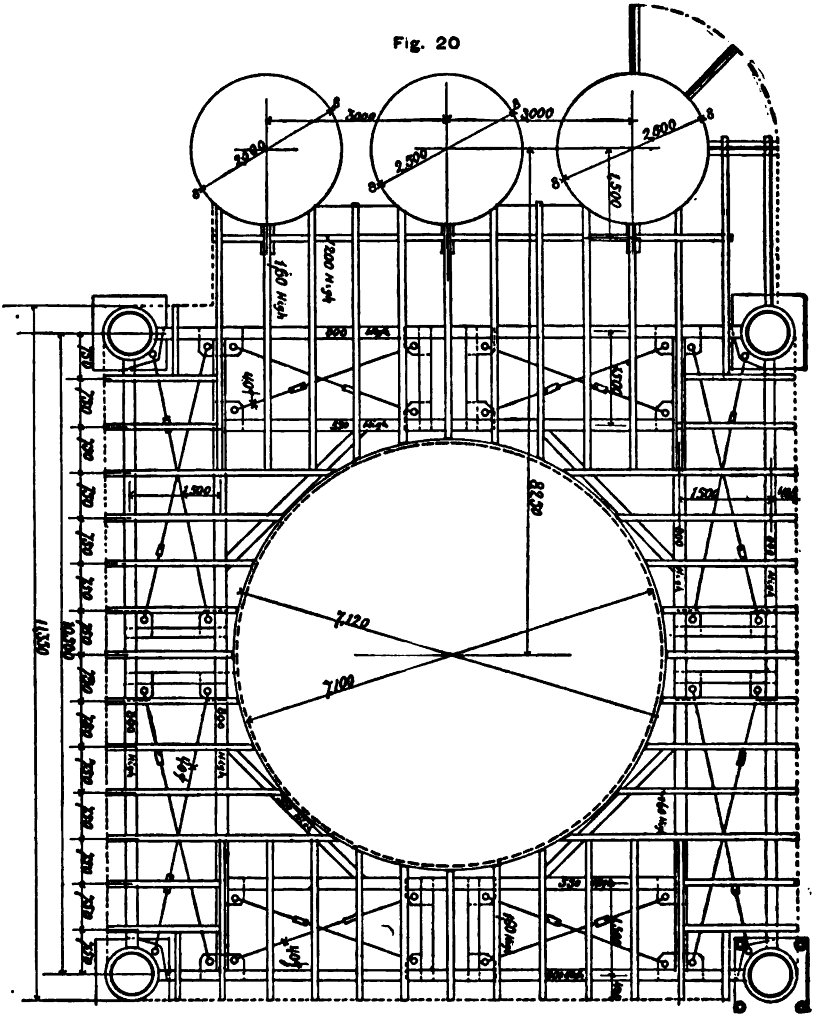


Plan of Closed Top and Charger of No. 1 Blast-Furnace at Friedenshütte.

wherever the blast-furnace manager is not troubled with lead and zinc in the ores. The tuyeres are always cooled; but the form first introduced by Hilgenstock at Hörde (see Fig. 26) is frequently used instead of the ordinary closed form.

Brick hot-blast stoves are so nearly universal that iron stoves can be found at few works. The former have proved economical wherever the blast is to have at least 600° C. of temperature. With well-built iron-pipe stoves, 500° to 550° C. can be maintained

Fig. 20



Plan of Frame for Top Platform of No. 1 Blast-Furnace at Friedenshütte.

without difficulty, as is proved at Gleiwitz. The opposition to brick stoves lasted longest in Upper Silesia, where the immense quantity of zinc-dust (oxide) carried by the tunnel-head gas rendered the economy, and even the operation, of such stoves problematical. When they were finally adopted, their employment required a careful pre-cleansing of the gas, which was performed first in the dry way, afterwards by means of water-spray; and it is still necessary, in cases (frequent in Upper Silesia) where the ores carry zinc, to blow out the stoves by letting the blast pass through them for a brief period (often not more than a second) before admitting it to the blast-furnace.

Fig. 21

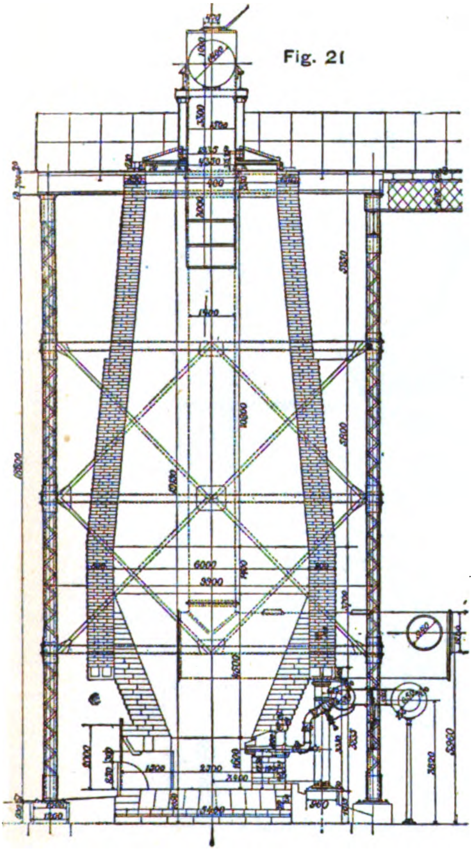
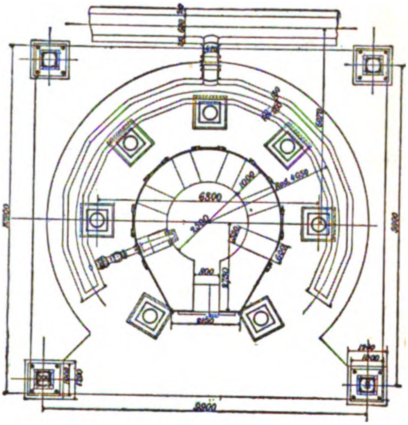


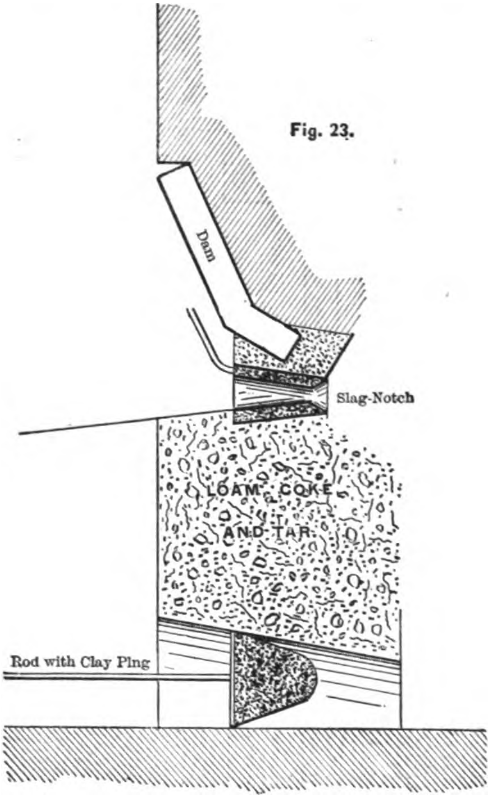
Fig. 22



Blast-Furnace at Hörde, Westphalia.

Iron stoves have been, and will be with good reason, retained where a low-silicon grey or mottled iron is made, especially for chill-castings; to which end, it is true, a *cold* blast is not, according to the ancient prejudice, necessary, but the blast should not be hotter than 300° C. It is certainly an error to employ brick stoves for low temperatures. They give their best results at a blast temperature of 900° C. In form, these stoves have followed the well known line of development, from the original checker-work to vertical cylindrical or prismatic flues.

Fig. 23.



Fore-Hearth, Cinder- and Iron-Notches of a Blast-Furnace at Hörde.

For a long time difficulty was encountered in so conducting the burned gases as to heat uniformly the entire cross-area of the apparatus; and Engineer Böcker, at Friedenshütte, near Morgenroth, in Upper Silesia, effected an important improvement when, instead of giving a uniform cross-area to his gas-flues, he made

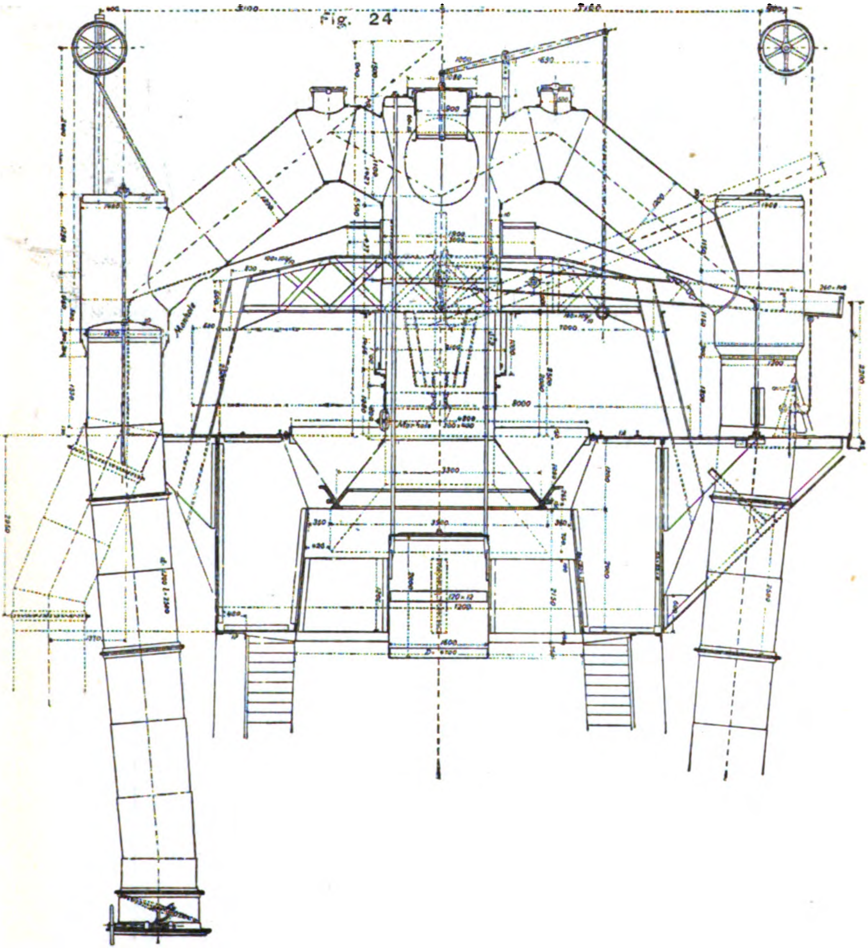
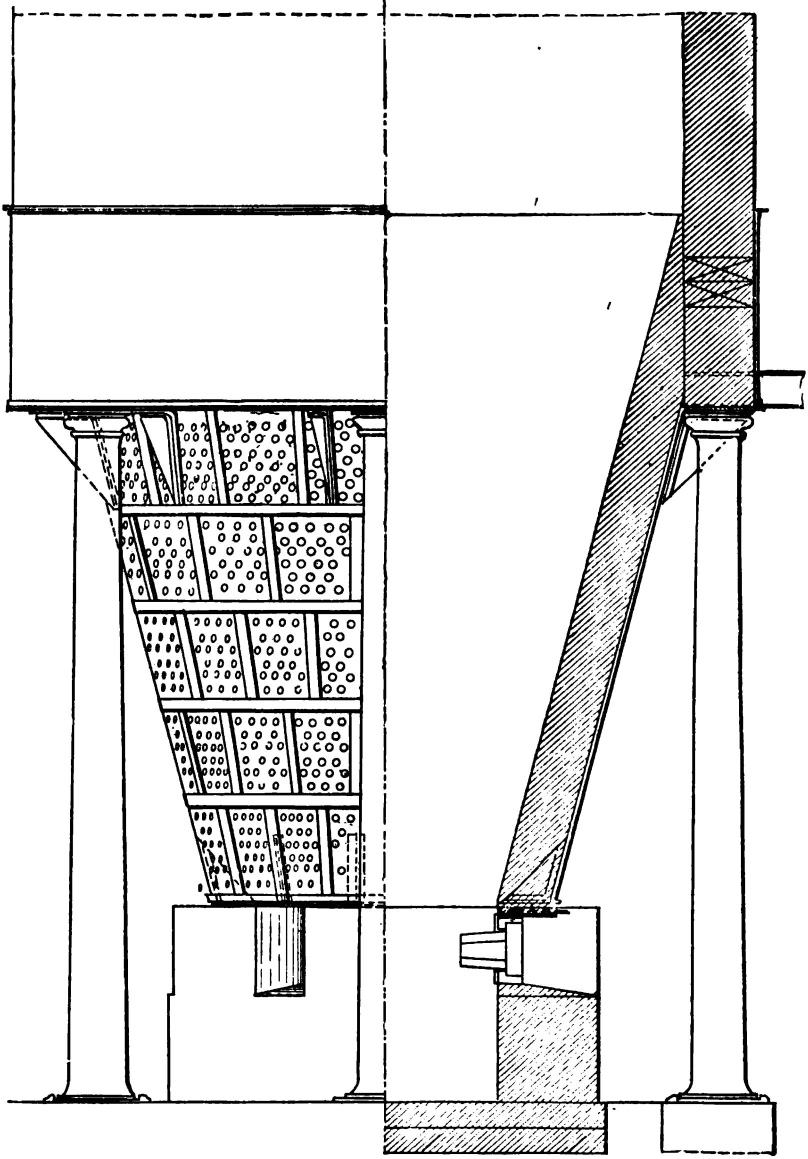


Fig. 24

Parry Cone and Gaspipe of Metz & Co.'s No. 3 Blast-Furnace at Esch.

those in the centre, where the gases traverse the shortest path, smaller than those at the sides, through which the path is longer. Fig. 27 shows his construction. The same end has been sought

Fig. 25.



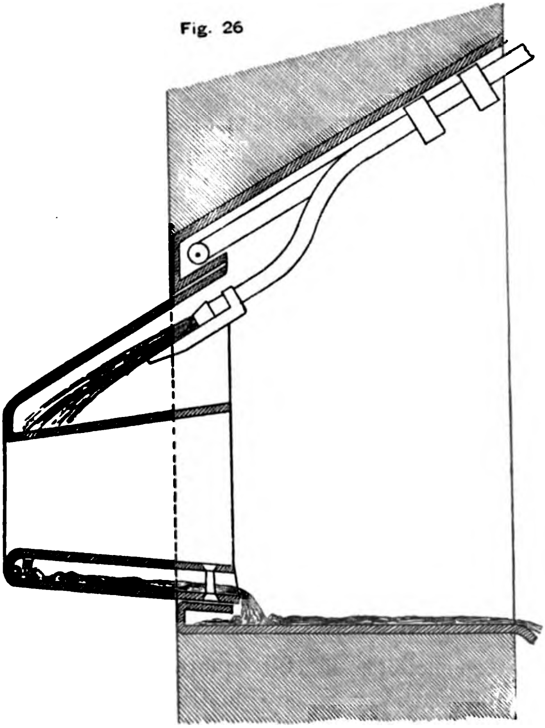
Lürmann's Construction of Blast-Furnace Bosh and Hearth.

of late in Luxemburg by means of slide-valves, apparently a less simple and effective device.

To prevent the gas from striking back into the blast-pipe, the simple Steffen "spectacles" (*Brillen*), shown in Figs. 28–31, are largely employed.

The blast-furnace gases are, of course, primarily used for heating the blast, but secondarily, also, in raising steam, particularly for the blowing-engines. A disaster at Friedenshütte, in Upper Silesia, which spread consternation throughout the whole district, namely, the simultaneous explosion of a set of twenty-two boilers, heated with blast-furnace gas, gave rise to a thorough re-examination of the subject of firing under boilers with gas. While it was proved that even a serious gas explosion under such circumstances could not possibly produce, of itself, such frightful effects as this

Fig. 26

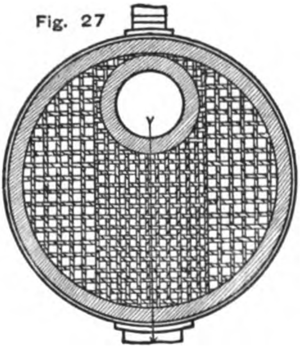


Water-Cooled Tuyere at the Hörde Works.

instance presented, still it was not quite disproved that the impulse to the beginning of a steam explosion might possibly be occasioned by the accumulation and subsequent explosion of unburned gas in the flues beneath and between the boilers. All the witnesses of the Friedenshütte catastrophe became its victims, and a complete explanation of it can never be given. But in rebuilding the boiler department of the works, great care was exercised to secure, by means of regenerators in front of the gas-jets, the spontaneous and certain ignition of the gas current whenever, after any brief intermission, it may be again directed under the boilers.

Fig. 32 shows this arrangement at Friedenshütte. The following statement shows the economic gain from a similar arrangement at Hayinge, in Lorraine:—Before the use of regenerator firing, in fifteen boilers, of 100 square metres heating surface, there was produced, per square metre, per hour, 16 kilos of steam; afterwards, 20 kilos. At Friedenshütte the gain is still greater, 14 kilos of water, per square metre, per hour, being evaporated, as against 8 to 8·5 kilos before the regenerators were used.

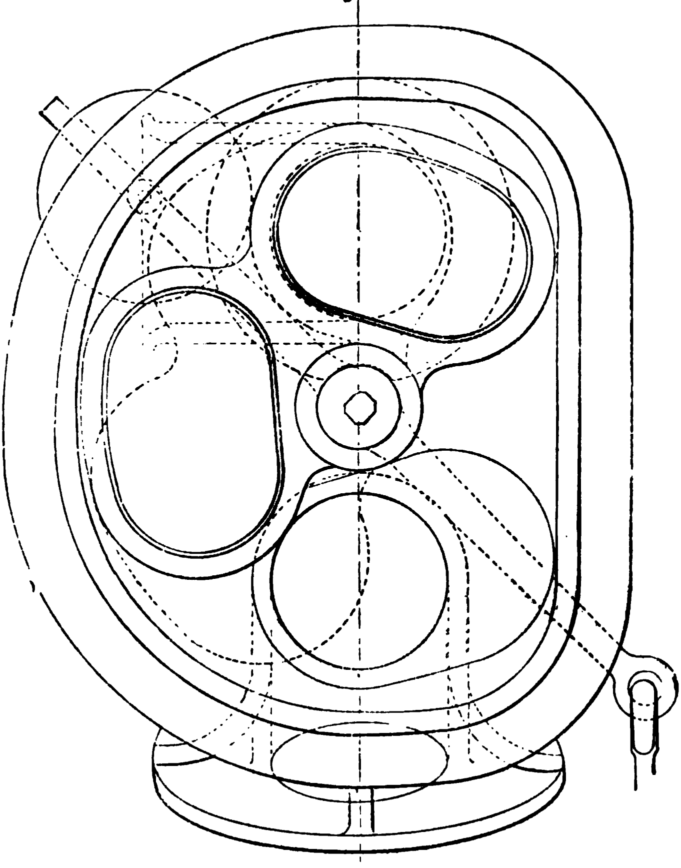
Fig. 27



Arrangement of Checker-Work for Hot-Blast Stoves at Friedenshütte, Upper Silesia.

Pig iron is used, according to the market demand for its employment, in the cupola, puddling-furnace, Bessemer acid or basic converter, or open-hearth furnace, or in casting direct, without remelting. The distribution of the total product among these several classes is given on a subsequent page. There is a remainder of *Bruch-eisen* and *Wasch-eisen* (furnace-scrap sorted or washed from sand, cinder, &c.). That we are, as a rule, far behind American practice in the amount of daily product is easily explained by the leanness of our ores. If, upon such lean ores, we should blow harder, the result would be an imperfect reduction and a scouring cinder. Nevertheless, our performance is not contemptible, as the following examples may show:—

Fig. 28.

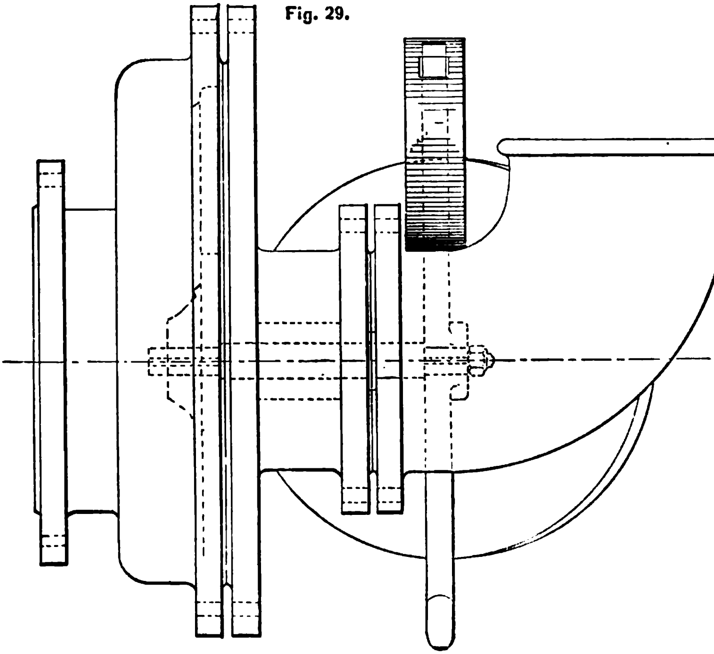


Front View of Gas Cut-Off for Blast-Furnace.

At Gleiwitz, a furnace of 255 cubic metres capacity, with blast heated to only 500° C., in iron stoves, produces daily, and with regularity, from a charge carrying 37 per cent. of iron, 61 metric tons of pig, upon a fuel consumption of 95 kilos of coke to 100 of pig.

At other works in Upper Silesia, where the blast is heated in brick stoves to 700° or 800° C., 72 tons, per twenty-four hours, are produced in furnaces, of 300 cubic metres capacity, from a charge containing 30 per cent. of iron; but the consumption of coke, per 100 kilos of pig, amounts to between 120 and 130 kilos.

Fig. 29.

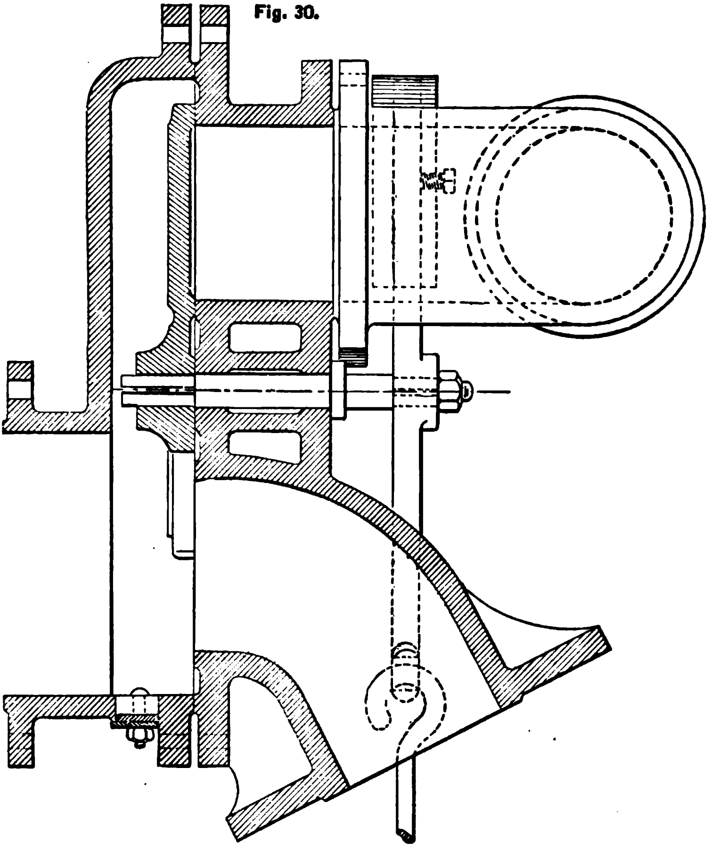


Side View of Gas Cut-Off for Blast-Furnace.

At a few works the conditions are much more favourable. At Friedenshütte, the newest furnace, of 278 cubic metres capacity, charged with 70 per cent. Upper Silesian ore, 25 per cent. cinder, and 5 per cent. Hungarian spathic ore, produces 80 to 90, sometimes 100, tons of Thomas pig per twenty-four hours, consuming 120 to 130 kilos of coke (containing 12 per cent. of ash) per 100 kilos of pig. The ore-mixture contains 33 per cent. of iron, 0·4 of lead, and 0·4 of zinc. The dolomitic limestone flux contains from 1 to 2 per cent. of zinc.

At Ilsede, where a very uniform mixture of phosphoric brown hæmatite kidney ore (*Bohnerze*) is used without fluxes, and yields 35·7 per cent. of iron, the coke consumption per 100 kilos of pig is 89·7 kilos (sometimes running down to 79·1 kilos), and the average product is 181·4 metric tons in twenty-four hours, while occasionally 190, and even 200, tons have been reached.

Fig. 30.



Section of Gas Cut-Off for Blast-Furnace.

At the Rhenish Steelworks, where the blast-furnace charge consists of one-third *minette* (oolitic brown hæmatite) and two-thirds domestic and foreign ores, the average daily product from two furnaces is 320 metric tons.

In contrast with the relatively simple nature of the charge in the works above named, the conditions as to ore-mixture are, in Westphalia, highly complicated. At Hörde it is necessary to mix from twelve to fifteen different kinds of ore; and at Oberhausen, the largest German blast-furnace establishment, up to thirty kinds are mixed for the charge. The following table illustrates the practice at Hörde:—

Composition of a Bed prepared for Charging, at Hörde.

Parts.	Ores, &c.	Fe.	Mn.	Al_2O_3.	CaO.	MgO.	SiO_2	S.	P.	Loss by Heating
		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
2,500	Roasted blackband, mined by the Company	45·62	1·78	10·00	5·58	2·52	12·54	1·17	0·70	...
1,000	Crude blackband, mined by the Company	29·12	1·34	4·33	2·74	1·56	8·97	0·23	0·40	40·25
2,000	Westphalian puddle cinder	53·87	5·00	...	...	...	10·50	...	3·10	...
500	Westphalian hammer cinder	60·01	...	...	...	...	12·37	...	3·04	...
500	Siegerland manganese slag	45·77	13·62	...	...	...	16·74	...	0·99	...
500	Puddle cinder from the Saar	59·56	1·07	...	...	...	8·44	...	4·89	...
500	Forge cinder, produced by the Company	50·23	...	...	...	...	32·61	...	...	...
750	Brown hæmatite from the Lahn	42·85	1·22	4·54	1·74	1·00	24·20	...	0·53	9·13
500	Red hæmatite from Sauerland	24·15	0·24	1·23	31·65	1·11	5·47	0·02	0·15	25·05
1,250	Manganiferous iron ore from Greece	32·65	16·89	2·29	6·27	3·04	5·79	0·19	0·35	14·18
2,600	Limestone from the Lenne *	0·20	...	...	51·14	2·18	0·73	...	...	43·54
12,600										

These conditions and, consequently, the proportions of the mixture are constantly changing, so that analyses of the several ores must be continually made.

The ores of Lorraine and Luxemburg carry a proportion of phosphorus which fits them for the manufacture of Thomas pig, containing about 2½ per cent. of phosphorus; but they carry also an amount of sulphur which requires, as I have already intimated, the addition of manganiferous ores. In the northern part of Lorraine, it is true, a self-fluxing ore-mixture can be made out of suitable proportions of the different varieties; in the southern part the addition of limestone is necessary. It is the general rule in Germany that limestone is required; the only exception, outside of Luxemburg and part of Lorraine, being the works at Ilsede.

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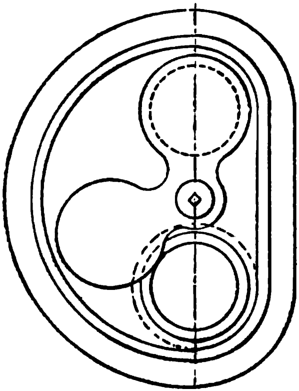
* The proportion of limestone is 26 per cent. of the total ore.

The relative proportion, in the pig-iron product, of the different classes of pig, has greatly changed since 1876, as the following statement will show :—

Fig. 31.



Spectacles in Gas Cut-Off for Blast-Furnace.

Classes of Pig.	Production in Kilotons.	
	1876.	1889.
Foundry	117	610
Forge (for puddling)	1,843	1,965
For ingot iron (including cast steel)	341	1,907
For direct casting (including *Bruck-eisen* and *Wasch-eisen*)	45	43
Total pig iron	1,846	4,525*

That is to say, the production of pig for ingot iron, which was, in 1876, only one-fourth as great as that of pig for puddling, now exceeds the latter; and the product of direct castings from the blast-furnace, without re-melting, has decreased not only relatively, but absolutely.

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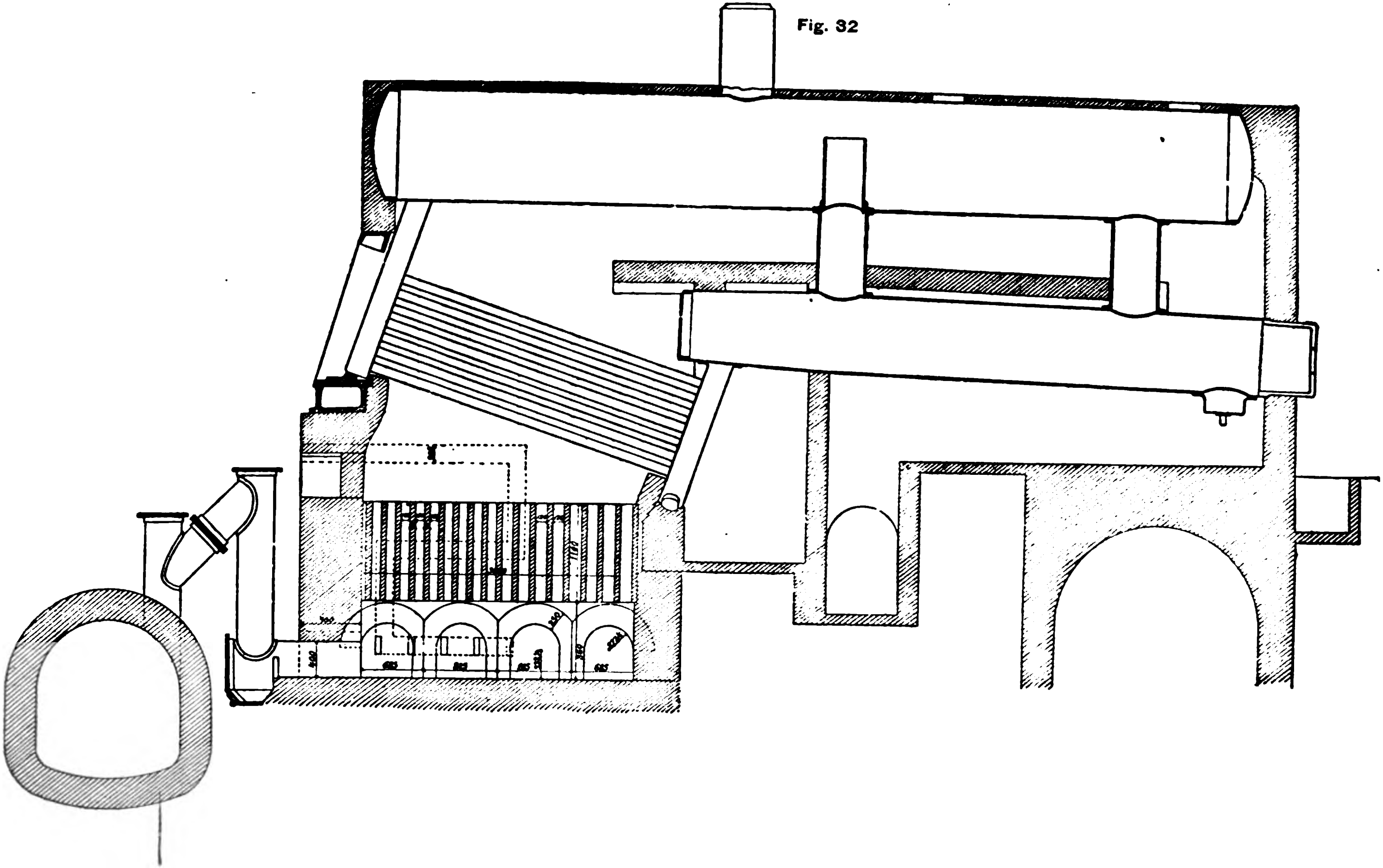
* Of which only 25 kilotons were made with charcoal as fuel.

Fig. 32



Longitudinal Section of Gas-Fired Boiler at Friedenshutte, Upper Silesia.

Ferro-manganese is regularly made in Germany in the blast-furnace, but exclusively at the Oberhausen works (the most extensive of the kind in the country), where all other kinds of pig iron are also produced.

The practice of subjecting the liquid iron direct from the blast-furnace to the fining (oxidising) process which it is to undergo is continually extending. The liquid pig is sometimes conveyed a long distance. At Hörde, for instance, it is carried by railway 2 kilometres (say 1¼ English mile) from the blast-furnace to the basic apparatus. The tapping of small casts at regular periods makes no trouble. The workmen quickly become accustomed to tap from the furnace into the ladle (which usually stands on a scale) the exact quantity required. Figs. 33–35 (Plate XXVI.) show the form of ladle-car used at Hörde.

The iron-notch or tapping-hole is kept during the cast as small as practicable, and when sufficient iron has run out it is stopped with a chamotte or clay plug on the end of a long rod. An adequate supply of such plugs, previously prepared by the keeper, is always on hand. When the tapping-hole has become gradually too short, it is opened and repaired; the space made for packing-in the new material being partly filled with loam, and a conical wooden block being laid in it, and tamped with a mixture of coke-dust and tar, over (in front of) which loam is pounded-in. The tar-coke mass stands excellently, like the bricks of similar composition already described.

The ladle for the molten iron is run in upon an inclined track between two furnaces.

Such a use of the liquid pig pre-supposes, it is true, a definite uniformity of operation in the blast-furnace. Where this cannot be maintained, the only resort (provided several blast-furnaces are running at once on a given class of pig) is to collect the liquid iron in a large reservoir or tank, in which the different grades can be mixed. These tanks are built solid—not tilting (as contemplated in Jones's German patent, No. 50,250)—and usually hold at least 80 metric tons of pig iron.

The utilisation of blast-furnace slags has long been a problem of great practical difficulty, but the increased production of slags rich in lime has led at last to a commercial application far more extensive than all others, namely, the manufacture of cement—

the so-called *Schlackenpuzzolanicement.* As a general rule, the slags designed for this use must be cooled by running them into water. The slag thus granulated can be easily ground with slacked lime, yielding a cement of sufficient strength for most purposes, and generally possessed also of hydraulic properties.

For some time it was attempted (and with reported success) to add to Portland cement, without injuring its quality, a considerable proportion of ground blast-furnace cinder. To this the manufacturers of Portland cement very properly objected. Now the cement made from slag is frankly called by its own name, and is not less esteemed in the building trade on that account.

Nothing new has been added during the period under consideration to the German practice in other methods of utilising blast-furnace cinder, such as the ballasting of railways, road-making, paving, the manufacture of mineral wool, &c.

I give below, in detail, an example of our practice in the manufacture of Thomas pig, and another illustrating the manufacture of ferro-manganese.

Manufacture of Basic Pig at Hörde.—As a type of the manufacture of pig iron for the basic Bessemer process, we may take the works at Hörde, where, as already observed, the liquid pig is directly converted into ingot iron. The Hörde furnaces (shown in Figs. 21 and 22) are specially arranged for the production of Thomas pig; and the furnace-lines and other features of the four stacks devoted to this manufacture have been determined with reference to it. Each furnace produces in twenty-four hours from 100 to 130 metric tons of pig iron, using in coke from 85 to 90 per cent. of its weight of product. A fundamental requirement of the process is uniformity of quality in the pig. The object is to obtain a pig iron containing up to 3 per cent. of phosphorus, 2 of manganese, not over 0·15 of sulphur, and not over 0·5 of silicon. This blast-furnace practice completely fulfils this requirement, although, as already observed, it has to contend with great obstacles in the number and variety of the ores used, necessitating very difficult mixing. Derangements of the furnace-working by the leakage of water into the hearth have not occurred for years; that is to say, not since the open tuyeres were adopted. It is, moreover, highly important to avoid an evil often very serious in the manufacture of Thomas pig, namely, the so-called lime-trouble or excessive basicity of the cinder. As soon as the influence of an excess of lime begins to appear in the slightest degree, it is counteracted by the timely addition of highly fusible silicates. The presence of manganese is notoriously advantageous to the running of the furnace, but superfluous during the heat in the converter. A high proportion of manganese in the furnace-charge is therefore carried, partly to facilitate the furnace-work, but chiefly to counteract the sulphur. Experience has shown that 2 per cent. of manganese is generally an adequate protection against an excess of sulphur in the pig. In using the liquid pig direct from the converter, the presence of superfluous manganese is specially felt, because in that case (unlike the case of pre-melting in the cupola) all the manganese has to be oxidised in the blow. For this reason, the practice of treating high-sulphur Thomas pig by mixing it with high-manganese pig has been introduced in order to remove sulphur from the one and manganese from the other. Manganese, as is well known, acts upon the sulphide of iron, liberating metallic iron, and forming sulphide of manganese, which separates as a slag. Thus the excess of manganese is removed by means of the sulphur, which would otherwise render the pig unsuitable for the converter. In order to facilitate the reaction of manganese and sulphur, an arrangement is employed permitting considerable quantities of the two classes of pig to be treated together for a sufficient period. It is found that two parts of pig, containing 0·5 per cent. of sulphur, and one part of manganiferous pig, containing only 0·02 per cent. of sulphur, produce a pig with only 0·1 per cent. of sulphur, and still containing 1·5 per cent. of manganese. The separated manganese sulphides, which carry also silicates from the oxidisation of silicon in the bath, and from the lining of the vessel, are utilised as manganiferous additions to the blast-furnace charge. They contain up to 40 per cent. of manganese, and 10 to 15 per cent. of sulphur; but the sulphur which enters the blast-furnace as manganese sulphide has proved to be entirely harmless.

The flue-dust of the blast-furnace gas-firing at Hörde contains a surprising amount of sulphate of potash, which is saved by leaching and evaporation, yielding a sulphate containing about 40 per cent. of potassa.

Manufacture of Ferro-Manganese at Oberhausen.—As already observed, ferro-manganese is made in the blast-furnace at Oberhausen. The ores come chiefly from the Caucasus, Greece, and Chili. They are pyrolusites, carrying 50 to 55 per cent. of manganese. The variable ores of Weilburg, on the Lahn, are used also to some extent. As a mixture, brown hæmatites with 20 to 30 per cent. of iron and 14 to 21 per cent. of manganese are utilised; they come from the Lahn and Carthagena.

The ferro-manganese produced contains from 30 to 87 per cent., averaging 66 per cent., of manganese. When it carries over 82 per cent., it disintegrates very soon into small pieces and powder, and can, therefore, be shipped in tight boxes only. Of the manganese in the charge, 60 to 70 per cent. goes into the iron. The slag contains, in percentages: silica, 25; alumina, 15; lime (with calcium and barium sulphides), 45; and protoxide of manganese, 15.

The consumption of coke ranges from 190 to 210 kilos per 100 kilos of ferro-manganese—according to the percentage of manganese in the latter—the high manganese ferro requiring most fuel. The average product is 40 metric tons per 24 hours.

A very interesting feature is the immense quantity of graphite which, during the cast, separates from the metal and fills the air—evidently because the molten metal possesses, at the high temperature of the furnace-hearth, the capacity to alloy itself with more carbon than it can retain as the heat is lost.

III.—Malleable Iron.

A. *Wrought Iron.*

Puddling, which, after the invention of the Bessemer process, and still more so after the introduction of the Thomas process, was supposed to be rapidly approaching its extinction, has in Germany not only been maintained, but, in some respects, extended and improved. True, puddled iron relatively retreats, year by year, before the advance of ingot iron, but the change is a slow one. The annual product of wrought iron has increased since 1876 from 948 to 1655 kilotons, and the increase has continued during 1889, as the statement given below will show; while the product of ingot iron, which has, indeed, had a more rapid development, has advanced from 249 kilotons in 1876 to 2046 in 1889, having passed its older rival in 1887:—

	1886.	1887.	1888.	1889.
Wrought iron (kilotons)	1416	1625	1547	1655
Ingot iron ,,	1376	1738	1785	2046

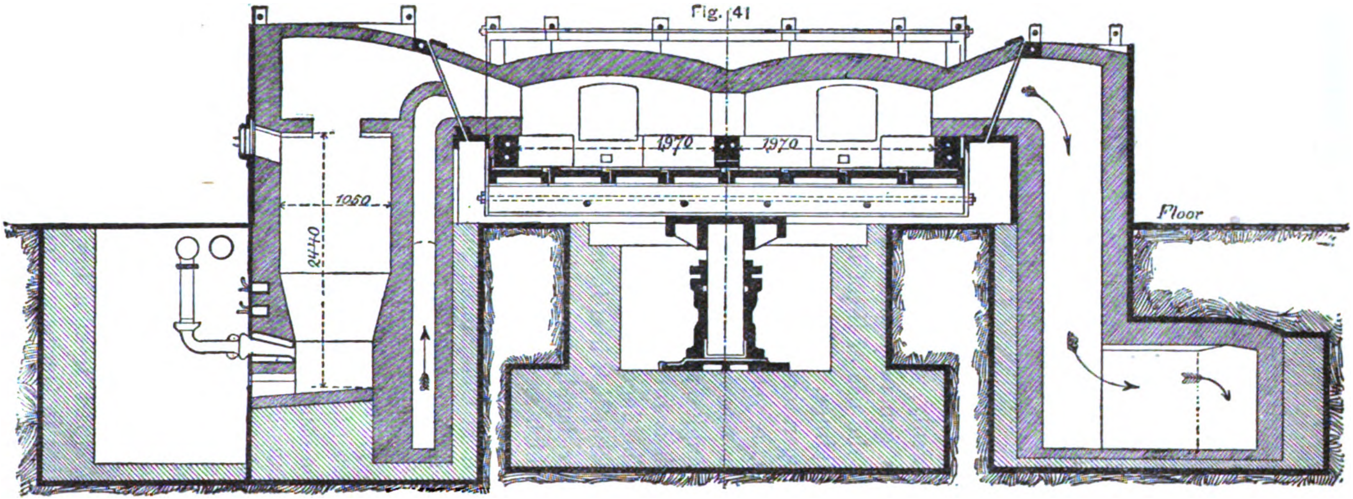
The reasons for this striking persistency in puddling lie partly in the obstinate prejudices of consumers, but partly also in certain real advantages possessed by wrought iron—namely, its relatively great ductility, the facility with which it may be welded, and the circumstance that, under excessive strain, it breaks gradually rather than suddenly, while its strength, though inferior to that of ingot iron, is generally uniform throughout to a trustworthy degree. While the use of ingot iron for large constructions, such as railways, buildings, boilers, and bridges, is constantly increasing, the small operator—the blacksmith or machinist—does not seem to be able, as yet, to get along without his wrought iron.

Ingot iron, however, is already used, not only for all rolled shapes, such as angles, tees, and beams, but for all varieties of merchant-bar, which is furnished, when desired, of a quality suitable for welding. The ingot iron of Peine is so pure that it can be used instead of Swedish iron in making horse-shoe nails.

On the other hand, less valuable ingot iron is rolled into cheap beams, which are still stronger than those of puddled iron, and have completely beaten the latter in the market. Such beams are rolled at Oberhausen and Neunkirchen, in sizes up to 400 mm. (15¾ ins.) in height.

Weld iron (wrought iron) is produced in Germany by puddling exclusively, and almost invariably by that variety of the puddling process (*Lüftfrischen*) which depends upon the air for oxidation. The other variety (*Erzfrischen*), in which oxidation is effected by means of a fettling of ore, and which is so common in America, finds among us a very subordinate application only.

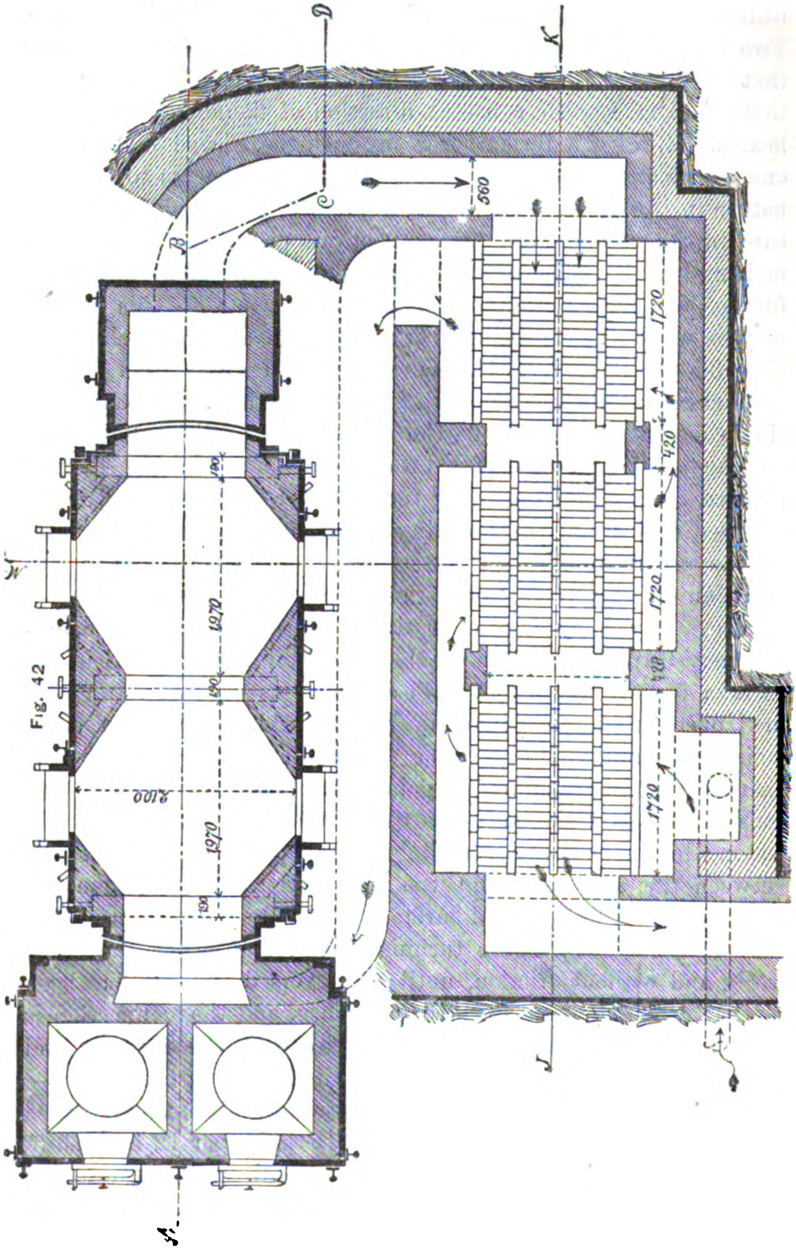
The essential improvements in puddling have not been in mechanical rabbling (though this has been done in the district of Saarbrücken and in Lorraine, without, however, changing the old construction), nor in the use of the rotary mechanical puddler (which, apart from a few small experiments, has never obtained a footing in Germany), but rather in the more complete



Pietzka Furnace.—Longitudinal Section on A B C D, Fig. 42.

utilisation of fuel, by means of gas-firing and double furnaces. Two furnace-designs deserve special mention in this connection: that of Springer, with fixed hearth and reversible flame; and that of Pietzka, with constant direction of flame and reversible hearth. Springer's furnace has two hearths, placed end to end, one of which is charged with pig, as the iron begins to come to nature in the other. The flame, brought to a very high temperature in the regenerators, passes from the puddling-hearth to the melting-hearth. The regenerators are in front of or under the furnace, as usual, and either vertical or horizontal. This furnace may be used with direct-firing or with gas-firing, and is shown in Figs. 36–40 (Plate XXVII.), as constructed for gas-firing. It has done excellent work, even with lignite as a fuel. It has but a single disadvantage, namely, the dependence of the two hearths on one another; and this led to the invention of the Pietzka furnace. While, in operating the Springer furnace, the flame is reversed only when the puddling in one hearth and the melting in the other are finished (or, in other words, must go in one direction as long as the puddling process lasts, even though, by reason of any delay or prolongation of the process, the regenerators may be more or less cooled), this objection is obviated in the Pietzka furnace, the latest form of which, as seen at Zawadsky, in Upper Silesia, is shown in Figs. 41–44. Here the flame maintains one direction, yet the hottest flame always strikes the hearth in which puddling is going on. The peculiarity of the construction is that both hearths are carried on a hydraulic piston which stands underneath, between them. The connections between the side-walls and the fixed fire-chamber or flue are made with inclined conical surfaces. The hydraulic piston lifts the hearths a little before turning them; and hence they turn freely and without friction, until the reversed position has been reached, when they are lowered into place, and the connection is again complete. The results of practice with the Springer and Pietzka furnaces may be judged from the following examples:—

A Springer furnace at Königin-Marienhütte, Saxony, turned out in 1889 an average product of 8815 kilos per 12-hour shift, and in some weeks 10,000 kilos, with a coal consumption of 40 to 50 kilos. In Styria the consumption of lignite is 60 to 65 kilos (per 100 kilos muck-bar).



Pietzka Furnace.—Cross-Section on L M, Fig. 42.

A Pietzka furnace at Zawadsky, Upper Silesia, holding a charge of 500 kilos, produced, by direct-firing, 6280 kilos; by gas-firing, 6674 kilos of muck-bar, as the average per shift; in single weeks, however, the average was 10,000 kilos of muck-bar, the coal consumption being 66 kilos per 100, with direct-firing, and 42 kilos with gas-firing. The escaping gases were here

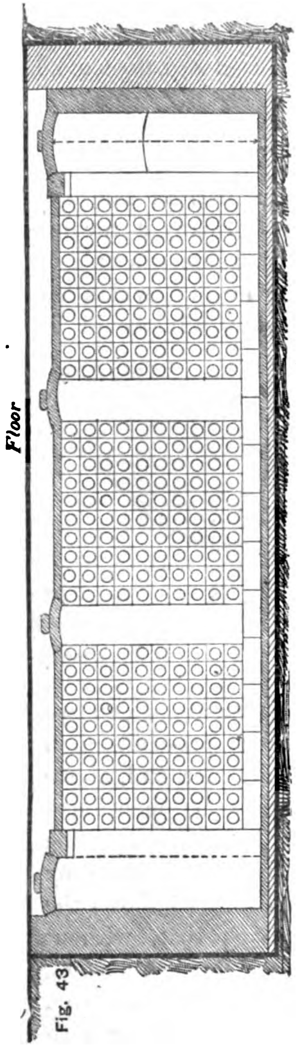


Fig. 43

Pietzka Furnace.—Longitudinal Section on J K, Fig. 42.

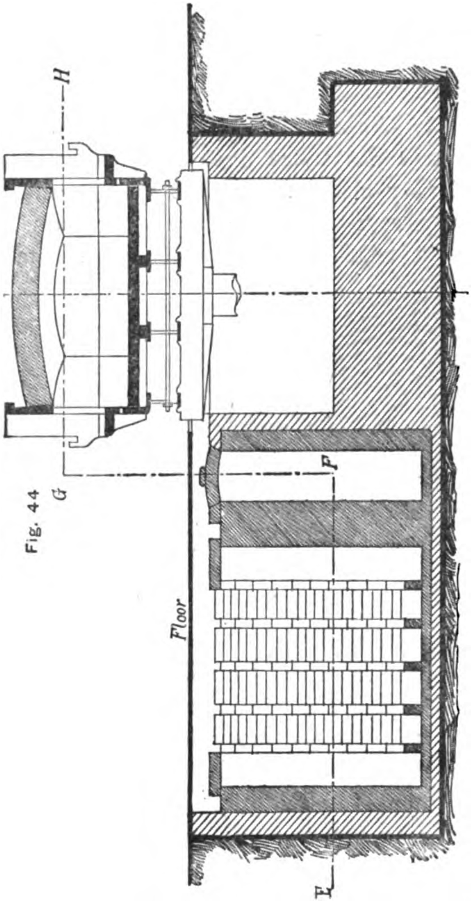


Fig. 44

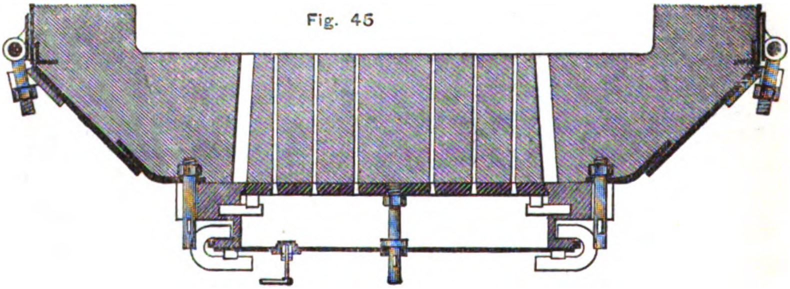
Pietzka Furnace.—Horizontal Section on E F, G H, Fig. 44.

utilised further in the production of steam. The latter record is specially favourable, since, deducting the amount of coal practically burned for the steam-power required in the operation of the furnaces, it shows only 28 to 29 kilos of coal used in puddling proper, while if all the gas were used to heat the regenerators, this figure would be further reduced to between 20 and 25 kilos.

B. *Ingot Iron.*

1. *Converter Metal.*—The production of ingot iron in the converter has twice since 1876 experienced in Germany a revolutionary change. In that year it was the admirable example of American works, far surpassing ours in their results, which led to a transformation of German establishments. It would be superfluous here to enumerate all the arrangements which we adopted from the United States: the continuous pre-melting in the cupola, the continuous operation of the converter, and, above all, the Holley movable converter-bottom, may be mentioned as the three most important. With regard to the movable bottom, Holley's original construction was abandoned, little by little, in favour of the draw-bottom, of which Fig. 45 shows the usual form, and which has the great advantage that, without breaking the blast-connections, the wind-box only being removed, the bottom can be drawn out and replaced with a fresh one. With regard to the air-passages, some have used bottoms with grouped tuyere holes, and others the tuyere-bottom (Düsenboden) of Lilienstern, but neither has shown, in the acid Bessemer process, any marked superiority over the other.

Fig. 45



Draw-Bottom for Converter.

Much more extensive was the second transformation of practice, after the introduction by Thomas of the dephosphorising process. The most important discovery of this eminent man (whose too early departure the German technical world mourned with his fellow-members in this Institute) owes its practical development to the perseverance of the two German licensees under the patent, namely, Hörde and the Rhenish Steelworks.

The great importance to Germany of the basic process is indicated by the product, which between 1883, the first year of its complete success, and 1889 has increased more than fourfold, and now constitutes more than a half of the world's aggregate product of basic metal. The chief reason is that most of the German ores, as has been observed already, are high in phosphorus, and hence entirely unsuited for the acid Bessemer process.

The original attempts of Thomas to make a basic lining from dolomite, with the addition of water-glass, small amounts of clay, and other siliceous substances, speedily came to an end, as did the numerous experiments of others who stood upon his shoulders, and who tried to substitute various materials, such as bauxite, for dolomite or magnesite, or to replace the binding material with something else, such as gypsum, starch, &c. All came back at last to the simple basic lining of burnt dolomite, mixed with anhydrous tar. The German converters, as a rule, are lined with this mixture by stamping, except at the throat, where bricks of it are used. All repairs of lining are likewise made with tar-dolomite. In single instances machine-pressed bricks have stood well.

The bottom of the basic converter is almost universally the tuyere-bottom, stamped with tar and dolomite, and arranged as a draw-bottom. The use of acid tuyeres (tuyere-groups) in a basic lining has practically disappeared. Nor is the preparation of these bottoms difficult. It requires only special care, upon which, rather than upon small variations in composition, the durability depends. Suffice it to say, that at present a bottom generally lasts through 25 heats, though instances are by no means rare in which 30 to 50 heats have been blown without removing the bottom. The lining itself lasts for 150 to 160 heats.

It should be added that the attempt to make the converter-bottoms by machinery, where they had formerly been carefully stamped by hand, has not met with approval. At least, the arrangement devised for this purpose at Bochum has not been extensively adopted.

The converter is usually lined *in loco*, without displacing it. An exception is presented at Neunkirchen, where it has been found better, after loosening half of the journal-ring, to remove the converter by means of a car, and reline it in a separate building.

The liquid pig from the blast-furnace is charged into the converter wherever this course is at all practicable. Of course, all localities will not permit it. Sometimes—as, for instance, at Peine—special reasons (in that case the location of a trunk railway) seem to render it desirable to separate the converting department from the blast-furnace. On the other hand, it has been found (as already related of Hörde, where the blast-furnaces and the converters are 2 kilometres apart) that the transfer of the liquid pig over considerable distances exerts no unfavourable influence.

It has also been found that the most suitable pig is one which contains 2, 25, and up to 3 per cent. of phosphorus. This has necessitated in Upper Silesia, for instance, where the ores carry too little phosphorus, the introduction of phosphorus into the blast-furnace in the form of basic slag. In other places, as at Ilsede, the phosphorites formerly separated from the ores are added, in order to bring up the percentage of phosphorus.

The pre-melting of the pig, when it is not taken direct from the blast-furnace, is never done in reverberatory furnaces, but always in cupolas. Even in these, however, a heavy loss of manganese is unavoidable.

The period of the blow for all kinds of pig used in the basic process is proportionally much shorter than in the acid process, and never exceeds fourteen or fifteen minutes. It is, therefore, easy to make forty-five or more blows in twelve hours. This is, however, not done, because there is no necessity for such fast running at any of the works, save perhaps for a short period, when it is desired to make good the loss of product through a previous interruption of work.

The quantity of blast used in the after-blow, *i.e.*, in dephosphorisation, is universally regulated by engine measurement, *i.e.*, by the number of revolutions. It is found that in the basic process the blast-pressure which was usual in the acid process is too low, and that it is better at the outset to arrange the blowing-engines for a pressure rising, if necessary, to 40, or, still better, up to 45 lbs. gauge-pressure.

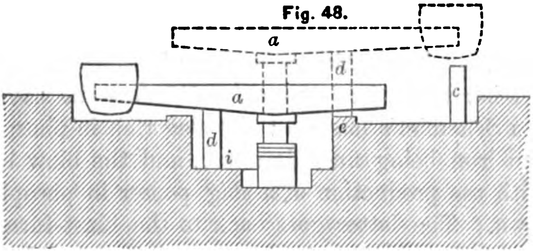
The belly of the basic converter holds generally from 7 to 10 metric tons of pig.

The basic slag (except where it is required, as already described, as a phosphoric addition to the blast-furnace charge) is sold for agricultural use. The farmers demand more of it than can be produced, since it has been found, if only ground to sufficient fineness, to yield without chemical treatment an excellent fertiliser for all kinds of soil, though best adapted to sandy, siliceous, and peaty soils. In most of the works, the slag is simply poured off from the bath and collected before the addition of ferro-manganese or spiegeleisen for deoxidation or recarbonisation. In some works, on the other hand—as, for instance, at Hörde—the slag is divided according to Scheibler's method; the slag rich in phosphorus and very poor in iron being first decanted, and the blow being then resumed with the production of a slag poorer in phosphorus and richer in iron. The latter goes back to the blast-furnace, while only the former is sold as a fertiliser.

For a long time many difficulties were encountered in the grinding of this slag to the extreme fineness required. The process created an enormous amount of dust; moreover, there was a constant segregation of the particles of iron mechanically contained in the slag. The slag-mills proved highly injurious to the health of the workmen, for whose protection against the dust very complicated arrangements, consequently, had to be introduced. Since it was proved, however, that properly constructed ball pulverisers would remedy completely the evil of the formation of dust, there has been no further difficulty from this source, and nothing now hinders the general use of this valuable product.

After deoxidation and recarburisation in the converter, the iron is tapped into a ladle, which, in basic works, is attached, as a rule, to a crane carried upon a locomotive. The fluid metal is conveyed to another room, where it is poured into ingot moulds. In some cases these arrangements are impracticable, perhaps because old acid plants have been adapted for the basic process, perhaps for lack of the necessary space in the locality itself. The latter is the case with the handsome works at Phœnixhütte, near Ruhrort. Here it is necessary to pass the ladle from one crane to another, as is shown in Figs. 46 and 47 (Plates XXVIII. and XXIX.). The same crane here serves to bring the ladle containing liquid pig from the blast-furnace, and to receive the ladle containing ingot iron from the converter. The latter ladle is delivered to a second crane, which stands in the centre of the casting-pit. Fig. 48 shows the arrangement here employed to prevent disaster occurring through a sudden failure of hydraulic pressure in the cylinder. It will be seen that if the crane *a* should suddenly sink while in the position indicated by the dotted lines, the ladle could not strike the mould *c* because of the leg *d* attached to the lower side of the crane-arm, which would be stopped in its descent immediately by the masonry ring *e*. To lower the converter farther, the foot *d* must be brought round to the recess *i*. This is the position shown by full lines in the figure.

Fig. 48.



Safety-Stop on Steel-Casting Crane.

It may be remarked here that there are many other devices for the protection of the workmen in this department, particularly at Neunkirchen, where there is a gutter beneath the floor, which serves in case of a break-down to direct the flow of molten metal to a pot; here, also, use is made of a blocking-tooth, which can be shoved into the rotating-gear on the axis of the converter so as to stop its turning, if, by any chance, the ram and rack of the hydraulic tilting device should fail to act. The vessel is generally so designed, however, that in every position its centre of gravity lies below its axis of suspension; in case of mishap it will, therefore, naturally return to its upright position.

Fruitless efforts have been made to overcome the imperfect desulphurisation in the basic as contrasted with the acid converter. Rollet's proposals have been carefully tested without being found practicable—at least from an economic standpoint. Endeavours have, therefore, been directed to the elimination of the sulphur in the blast-furnace. The method which has been operated successfully at Hörde reduces the proportion of sulphur by utilising the manganese, which eases the running of the blast-furnace, while it is unnecessary for the basic process. This practice has already been described. In order to illustrate converter practice, under given special conditions, the following details of work are set forth:—

Hörde.—Basic-converter practice at Hörde is carried on in the following manner:—The pig metal, weighed off in 10-ton charges, is brought to the converter in a tipping-ladle of the form shown in Figs. 33 to 35 (Plate XXVI.). Three converters are used in alternation. The lining consists of burnt dolomite brick for the throat, and rammed dolomite for the rest of the vessel. Formerly, the whole vessel was walled up with burnt tar-dolomite brick; but the ramming of the sides has proved preferable, and better, also, than laying up with unburnt tar-dolomite brick. The bottoms have seventy-two cylindrical holes, 17 to 18 mm. in diameter. With a blast-pressure of 30 lbs., the duration of a blow is nine minutes before decarbonisation, and five minutes after it. The phenomena during the blow do not differ essentially from those exhibited in blowing cupola-metal; at most the flame may be slightly delayed. Generally speaking, direct-metal works hotter than cupola-metal.

The necessary lime-addition amounts to 14 per cent. of the pig metal charged. At Hörde, two-thirds of it are introduced at the start; three minutes after dephosphorisation has set in, the metal-bath contains only 0·3 per cent. of phosphorus, while the slag, which is quite fluid, runs as high as 20 to 30 per cent. of phosphorus, and carries but little iron. This slag is separately poured off by Scheibler's method, and the balance of the lime is then charged. The iron that is unavoidably oxidised in the elimination of the residual phosphorus is taken up by the new slag, which, therefore, becomes excellent material for the blast-furnace, while the first slag is applied in agriculture. The operation of the basic process is shown in the accompanying tabulation of analytical results obtained from a series of gas-, metal-, and slag-tests, which were taken at equal intervals throughout a complete blow :—

Basic Heat. *No.* 882.

	Si. Per Cent.	P. Per Cent.	Mn. Per Cent.	C. Per Cent.	S. Per Cent.
Pig metal . . .	0·58	2·75	1·57	3·60	0·079
Sample 1 * . .	0·28	2·57	2·50	2·81	0·079
,, 2 . . .	0·07	2·08	0·30	2·02	0·073
,, 3 . . .	0·07	2·25	0·34	1·33	0·074
,, 4 . . .	0·06	1·55	0·26	0·71	0·079
,, 5 . . .	0·02	0·061	0·21	0·105	0·054
Steel	0·02	0·084	0·55	0·136	0·046

	SiO_2. Per Cent.	FeO. Per Cent.	MnO. Per Cent.	CaO. Per Cent.	MgO. Per Cent.	P_2O_5. Per Cent.	CaS. Per Cent.
Slag sample 1 *	9·20	0·55	8·87	76·10	4·86	2·94	0·63
,, ,, 2 .	9·50	0·73	9·70	71·40	5·33	6·90	0·34
,, ,, 3 .	9·30	2·30	8·42	66·17	6·47	7·32	0·31
,, ,, 4 .	10·28	7·13	9·45	50·71	6·90	15·87	0·27
,, ,, 5 .	6·99	11·98	5·40	46·84	4·09	24·73	0·52
,, ,, 6 .	4·79	26·03	4·62	42·05	6·83	16·33	0·65

	CO_2. Per Cent.	O. Per Cent.	CO. Per Cent.	CH_4. Per Cent.	N. Per Cent.
Gas sample 1* .	3·5	8·1	2·0	0·9	85·0
,, ,, 2. .	3·0	3·0	10·6	1·0	81·4
,, ,, 3. .	3·0	0·3	28·3	1·6	66·6
,, ,, 4. .	1·8	0·2	29·8	1·8	65·0
,, ,, 5. .	1·2	0·8	1·6	0·9	95·6

Important reactions occurring between sample-periods (4) and (5) are not shown in this table; but many special investigations have proved that, during dephosphorisation, manganese returns to the metal-bath, where it effects an elimination of sulphur. In proof of such behaviour, the following analyses of samples from the bath, taken March 16, 1887, may serve :—

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* Samples of metal and slag were taken *after* the corresponding gas samples.

	Mn.	P.	S.
	Per Cent.	Per Cent.	Per Cent.
Heat No. 184.—Upon disappearance of spectrum line .	0·19	2·070	0·133
,, ,, At second lime-addition	0·62	0·463	0·067
,, ,, Upon addition of FeMn. Steel test .	Undetermined.	0·110	0.052
,, No. 185.—Upon disappearance of spectrum line .	0·24	2·180	0·072
,, ,, At second lime-addition	0·81	0·718	0·042
,, ,, Steel test	Undetermined.	0·075	0·026
,, No. 186.—Upon disappearance of spectrum line .	0·24	2·390	0·081
,, ,, At second lime-addition	0·79	0·483	0·047
,, ,, Steel test	Undetermined.	0·082	0·056

This reaction cannot create surprise, since it is well known that the manganese of the ferro-manganese, added for deoxidising and recarbonising, likewise induces a removal of sulphur. That sulphur actually volatilises from the vessel is indicated by the fact that the slag from highly sulphurous charges contains no proportional increase of calcium sulphide, so that the elimination of sulphur from the metal exceeds what is thus accounted for in the slag. More striking than the volatilisation of sulphur is that of phosphorus. It depends on temperature, and at times, with hot heats, reaches 30 to 40 per cent. of the total phosphorus; but with cold heats this elimination ceases almost entirely. Tests have determined that, with like percentages of phosphorus and like quantities of lime, the resulting slag has shown at one time twenty parts of phosphoric acid to fifty of lime, and at another time thirty of phosphoric acid to fifty of lime, according as the heat ran hot or cold.

All attempts at a regular production of high-carbon basic ingot iron have failed here, as elsewhere. Probably the method of carbonising the metal by means of carbon, as introduced at the Phœnix Works, and previously alluded to, may be a step in the right direction. The ingot iron of Hörde generally carries 0·5 per cent. manganese, and is put on the market with a wide range of carbon, and also with welding properties, if demanded. For the material used in the current manufacture of rails, ties, &c., a large number of analyses has shown that, with 0·5 per cent. manganese, 0·07 per cent. sulphur is harmless, while 0·07 to 0·10 per cent. sulphur will betray its presence in the number of rejections in the rolling-mill, and anything over 0·10 per cent. renders the product useless. These limits have been sharply defined in the course of years by subjecting to accurate chemical analysis every defective or worthless product of the mill.

Phœnix.—The basic Bessemer works at Phœnix, near Ruhrort, were built in 1884, and put in operation toward the end of the same year. The necessity for filling-in the ground of the whole plant to a depth of 8 metres increased considerably the difficulty of providing proper foundations, and led to the design of the lightest possible iron construction for all the buildings. Between the iron beams, the walls are panelled with half-brick. Space is limited, and hence the general arrangement which is shown in Fig. 49 (Plate XXX.). Direct metal from two blast-furnaces, producing 6000 metric tons a month, can be run to the converter-house by a locomotive. The same track also serves to bring in the remainder of the pig, which is melted in three cupola-furnaces. At Phœnix, the Thomas pig carries 2 to 2·4 per cent. phosphorus, 1·8 to 2·3 manganese, 0·2 silicon, 2·8 carbon, and 0·02 to 0·07 sulphur.

The three converters are served by one central charging and transfer crane, and by an independent casting-pit. The central crane takes the charging-ladle from its truck, and raises and swings it; two men on the upper platform of the crane empty the ladle into the converter; the crane is then lowered, and the blow begins as the vessel is righted. The second arm of the same crane is ready to receive the casting-ladle. Ferro-manganese is thrown into the converter from the platform of the transfer-crane. After a completed blow, when the casting-ladle has been picked up by the transfer-crane, the latter swings into line with a casting-crane, which, in turn, takes the ladle and does the pouring, while the transfer-crane is prepared to handle a new heat. The 1200-kilo ingots taken out of the moulds are charged into soaking-pits, which are not specially fired. Thence they pass to the blooming-train, and, after that, are cut up with heavy shears. The blooms are either sent to the billet or the plate mill, or go to other rolls for working up into a great variety of shapes.

The height of the three cupolas to the charging-door is 5·4 metres, the diameter at the tuyeres is 1·4 metre, and that of the shaft 1·8 metre. The level of the hearth is 2·4 metres above the floor. Each cupola melts 35 metric tons per hour, with 700 to 800 millimetres of water-gauge blast-pressure. The two blast-furnaces deliver, in twelve hours, 80 to 90 metric tons of molten pig, which is blown without admixture of cupola metal. The converter-charge is 11 tons, and the greatest record for twelve hours is thirty-three heats, or 315 tons. The monthly output amounts to 12,800 tons. The duplex blowing-engine has air-cylinders of 1450 mm. diameter, and 1700 mm. stroke; it is fitted with expansion valve-gear, takes steam at 90 lbs., and delivers blast at 27 lbs.; its speed is thirty-six revolutions per minute.

For the hydraulic machinery there are ten air accumulators.

Thirty-six non-fired Gjers soaking-pits receive the ingots, which usually measure 410 mm. square. The aggregate yield of the pits has reached 395,000 tons. The rolls of the reversing bloom-train are made of ingot steel 900 mm. in diameter and 2500 mm. long. The driving engine has cylinders of 950 mm. diameter and 1250 mm. stroke, and works with 90 lbs. of steam. The capacity of the mill amounts to 325 metric tons in twelve hours; 12,600 tons of blooms per month are rolled, ranging from 200 by 180 mm. to 130 mm. square in cross-section.

The transfer and the casting crane have each a central supporting column and two cylinders, one for the live and the other for the dead load. All motions, including the swing, are produced by hydraulic power, controlled by an operator on the crane. The same is true for all the soaking-pit and shear cranes, an operator being stationed on each. Piston valve-gear is used for all hydraulic valve-motions.

The interval between tapping the pig metal and filling the converter lasts three minutes for cupolas, and about twelve to fifteen minutes for the blast-furnace, though exceptional delays of two and a half hours may occur without creating difficulties in the blow. From the time of charging the converter till the cast is completed sixteen to eighteen minutes elapse; of this, five to ten minutes is required for casting, stripping, and picking up the ingots. The ingots remain in the soaking-pits for thirty to ninety minutes. The interval between lifting them out and cutting them into blooms may cover five to twelve minutes, according to their size.

Peine.—The basic converter plant at Peine, shown in plan, Fig. 50 (Plate XXXI.), is served by four cupolas that run with fan-blast. Four ten-ton converters make as high as twenty-eight blows in a twelve-hour turn. The pig carries 3·6 per cent. carbon, 2·7 phosphorus, 2 to 2·5 manganese, 0·06 silicon, and 0·04 to 0·06 sulphur. The cupola coke amounts to 6 to 6·5 per cent. of the weight of pig melted. More skilful mixing of the pig for the converter has permitted a reduction of the lime-addition since 1883 from 19·5 per cent. down to 15·2 per cent. of the weight of ingot metal. The consumption of chills amounts to 17 kg. per metric ton of ingot metal, the products being billets measuring 100 to 200 mm. on a side, and slabs 150 to 350 mm. thick, 200 to 800 mm. wide, and 700 to 1400 mm. long. The loss by oxidation in the converter has also been reduced from 15·22 per cent. to 13·35 per cent. On the other hand, the output, which was 13,520 metric tons in 1882, rose to 66,450 tons in 1885, and 101,893 tons in 1889, while this year it promises to reach 116,000 tons. The only iron used is Ilsede pig.

As regards the durability of the vessels, the lining which used to be worn out by 56 heats in 1882 now stands 162 heats, and the life of the bottoms has increased from 11 heats in 1882 to 28 heats at present.

The duration of the blow now averages 10·68 minutes, and the dephosphorising period (afterblow) 3·55 minutes. In the past year the works produced 12,000 tons of crude ingots. The rest of its product supplied one 640 mm. three-high billet train; one 860 mm. reversing plate-mill, and one rod and merchant mill having a 525 mm. roughing train, a 420 mm. middle train, a 350 mm. fast train, and a 260 mm. finishing train. One large rail and beam mill, designed to have two three-high trains with roll-diameters of 750 and 850 mm., respectively, is nearing completion.

In a twelve-hour turn, the billet train, served by a single heating furnace, makes 100 tons of billets from 200 mm. blooms that weigh 350 kilogrammes; the ingots are brought to the furnace hot by a locomotive transfer from the converter-house. The coal consumed for reheating amounts to 4·5 per cent. Last year's production was 47,000 tons of billets, with a waste of 2·7 per cent. The plate-mill turned out last year 6390 metric tons of

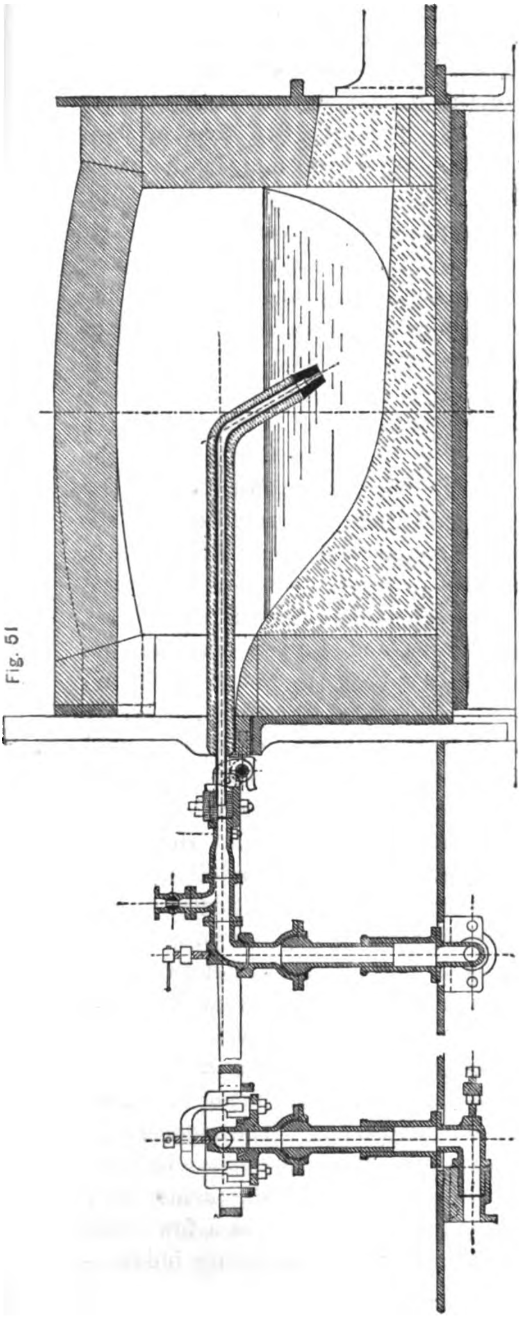

Fig. 51

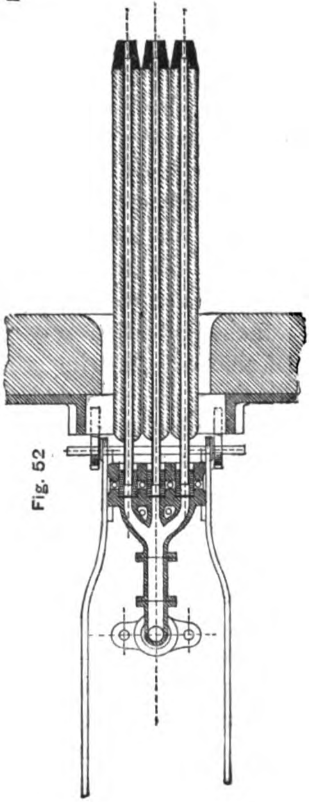

Fig. 52

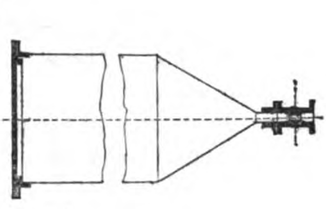

Fig. 53

Figs. 51, 52.—Apparatus for Injecting Air into Open-Hearth Bath.
Figs. 53.—Funnel for Use with Coal-Dust.

plate, varying from 5 to 30 mm. in thickness. The monthly record for March was 1050 tons. The product is principally used for boiler-plate. The work of the ingot-metal rod and bar mill last year amounted to 14,441 tons of rods, 1315 tons of flats, 1242 tons of shafting, ranging from 90 to 160 mm. in diameter, 5128 tons of mine rails, and 1514 tons of merchant bar. Altogether 77,788 tons of pig iron were used last year for the manufacture of ingot metal. The ingot shipments covered 5707 tons; the product amounted to 70,639 tons of ingots, and, besides 34,268 tons of billets, there were 4015 tons of plates, and 13,101 tons were turned out from the rod and merchant mill.

2. *Open-Hearth Metal.*—The manufacture of ingot iron in the open-hearth furnace is generally conducted in Germany by the Martin process, according to which pig iron is decarbonised by malleable scrap—commonly the crop-ends and rejections of the mill's own production. Ore or hammer-scale is employed only in small measure, usually as auxiliary to complete the decarbonisation. The regular pig-and-ore or Siemens process, if used at all, finds application only in isolated cases, and to a very small extent. Equally limited in its introduction has been the practice of blowing air into the metal; the special and, as it proved, perfectly practicable apparatus shown in Figs. 51 to 53, which was used for some time in the Phœnix Works at Ruhrort, has since been abandoned because economic advantages for it could not be demonstrated. The process is as frequently acid as basic; the latter method, however, is continually gaining ground, and it is especially interesting to observe that such works in particular as aim only at small output, or have but small quantities of scrap to work up, prefer the basic process. To such extent, indeed, is this true that even in ordinary machine shops and foundries 1·5 to 2 ton open-hearths are found in successful operation.

At the present day all furnaces for acid as well as basic working are designed with a high roof—a silent recognition of Frederick Siemens' principle of free-flame development. The regenerators are set below the general floor-level, but with free space between them and the bottom plates of the hearth; less frequently they are placed horizontally in front of the furnace, and in a few cases, as at Phœnix, they are of cylindrical design, standing independently. The substitution for checker-work of flues, as used in blast-furnace stoves, is steadily gaining favour.

The hearth-bottom is commonly prepared with tar-dolomite, though in recent practice calcined magnesite, dolomite, or limestone, with milk of lime or of dolomite as binding material, has also been employed. Repairs are made with a paste of tar-dolomite. As a rule, both bridge-walls are air-cooled; water-cooling is exceptional. Attempts have been made, and not without encouraging success, to water-cool the zone around the furnace most subject to wear, at the level where slag comes in contact with the walls. The roof is still in all cases made of silica-brick, and a mixture of chrome-iron ore and tar generally serves to separate it from the basic hearth. Pure magnesite brick or a layer of rammed magnesia is used more or less for the same purpose. Entire hearths of magnesia, on the other hand, are uncommon. The slight advantages which they may possibly possess over dolomite hearths do not, in Germany, compensate for their high cost. The roof, as well as the ordinary fire-brick walls which carry it, are always specially supported, so that no load from the roof is brought upon the hearth, or upon the separating layer. The size of the furnaces has steadily grown, though in Germany fifteen tons capacity has rarely been exceeded.

As a rule, uncalcined limestone serves for the basic addition; it is charged, at the same time, with the whole quantity of pig and scrap, the latter being commonly introduced between the two parts of the pig-charge. The earlier practice of charging the scrap in several lots is falling more and more into disuse; indeed, not the slightest disadvantage can be traced to the newer method. Every effort is made to shorten the charging-period, which, in the case of large charges, occupies much valuable time. At Phœnix, near Ruhrort, for example, the charging consumes two to three hours, during which the first part of the charge already melts. The remedy has been sought either in a greater number of charging-doors, with a correspondingly larger force of men, or in the adoption of hydraulic charging machinery.

Before the addition of ferro-manganese, the slag is drawn only if it carries much phosphorus. If low in phosphorus, the relatively thin and diffused cover of slag is not a disadvantage.

Basic open-hearth metal is generally regarded as an excellent material, for the reason that it is practicable to make accurate tests during its manufacture, and since not more than three or four heats can ordinarily be run in twenty-four hours, there is sufficient time for both chemical and mechanical examinations. A by no means unessential cause of the common preference for open-hearth steel over converter metal lies in the better opportunity offered by the open-hearth for a uniform distribution of the manganese introduced as ferro or spiegel. For the lack of such opportunity, much difficulty has heretofore been encountered in producing high-carbon metal in the basic converter. We may therefore welcome as a progressive step the practice introduced and developed at the Phœnix Works, in which the bath is deoxidised with a small addition of ferro-manganese, and then further carbonised by introducing a stream of pulverised coal. Not only is economy in the use of expensive ferro thus effected, but at the same time the product runs lower in manganese, and is consequently more homogeneous. Concerning the details of this practice I refer to Mr. Thielen's paper, to be read at this meeting.*

The following are illustrations of general practice:—

Hörde.—The Hörde Works have nine regenerative open-hearths for the manufacture of ingot iron; six are in constant operation, and three are undergoing repairs, warming up, &c. The fuel is water-gas. The newer furnaces measure 8 by 3 metres, and have a capacity of 15 metric tons, though the charge does not commonly exceed 10 tons. The capacity of the older furnaces is 7 tons. The hearth is made of dolomite, and the sides and roof of silica-brick manufactured at the works. The newer furnaces stand 300 to 350, and the older ones 180 to 250 heats. They are run with scrap, and about 20 to 25 per cent. of pig. Ore is used (Siemens process) only in small quantities, so far as it may serve to correct the carbon contents of the bath. If the scrap is in a convenient form, six heats in twenty-four hours can be made in the newer furnaces. These furnaces are also fitted so as to combine the basic and the Martin processes. For this practice Thomas metal is blown down to 0·3 per cent. phosphorus in the converter; to the limit, that is, at which the second lime addition would have to be made, and no considerable oxidation of iron has yet occurred. The Thomas metal is then conveyed in a ladle to the open-hearth, and there finished. One furnace can easily make eight to nine such heats in twenty-four hours, and the Thomas metal is thereby converted into excellent open-hearth steel. The choice of this practice depends on the supplies of scrap, and on the excess of converter output over rolling-mill capacity. The Hörde basic open-hearth steel is always, apparently, of better grade than the converter metal, even when no difference can be detected on analysis. The following comparison is to the point:—

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* *Vide* p. 564, *et seq.*

Thomas Steel (Converter Metal). Heat 265 contained:		Open-Hearth Steel. Heat 202 contained:	
Phosphorus	0·042	Phosphorus	0·046
Manganese	0·595	Manganese	0·580
Carbon	0·135	Carbon	0·137
Sulphur	0·037	Sulphur	0·046

It is to be noted that the basic open-hearth process removes little or no sulphur, so that its product averages relatively more sulphur than does converter metal, as the following figures taken at random from open-hearth heats will show:—

Heat No.	48.	51.	75.	84.	88.
Sulphur, per cent.	0·078	0·062	0·066	0·044	0·049
Phosphorus „	0·049	0·047	0·051	0·045	0·031

This as yet unexplained action is further illustrated by the following samples taken from one heat:—

Heat No. 954, *August* 25, 1888.

Sample.	Phosphorus. Per Cent.	Carbon. Per Cent.	Manganese. Per Cent.	Sulphur. Per Cent.
1	0·084	0·242	0·62	0·067
2	0·080	0·246	0·72	0·066
3	0·062	0·227	0·59	0·067
4	0·079	0·215	0·66	0·072
5	0·064	0·167	0·39	0·079
6	0·067	0·137	0·39	0·069
7	0·056	0·135	0·47	0·070
8	0·050	0·132	0·41	0·076
Steel sample	0·078	0·154	0·36	0·087

Apparently, open-hearth steel is less affected in its physical qualities by sulphur than converter metal. The effort to explain the difference in behaviour of the two metals by a difference in specific gravity has failed, the two kinds of ingot iron having been found to possess exactly the same specific gravity.

Phœnix.—The open-hearth works for the ingot iron manufacture at Phœnix consist of an old plant of four 10-ton furnaces and a new one of two 20-ton furnaces. All the furnaces are basic-lined, and work up the whole of the scrap made in the works, with malleable scrap of all kinds. The output amounts to 3200 tons per month. All grades of metal, ranging from 0·6 to 0·9 per cent. carbon, are produced and are principally manufactured into tires, axles, and high-quality plate and merchant iron. Recently the furnaces have been supplied with gas from ten fan-blown cupola producers, measuring 1650 millimetres in inside diameter, and 2800 millimetres above the grate.

IV.—ROLLING.

While the improvements that have been effected in mechanical arrangements have been treated in Mr. Daelen's paper, read at the recent New York meeting of the Institute,* attention will here be called to a few points only.

Ingot iron is now used in Germany for the greatest variety of purposes. It need not be said that rails are made of such metal exclusively. For this purpose, however, it is usual to employ only the metal from the converter. Railway-ties are also made of ingot metal, as is the greater part of the wire manufactured in the country.

For structural shapes, particularly angle and channel bars, and U, T, and I beams, steel is being more and more used, while for boiler-plates it has long been recognised as superior to wrought iron. The former prejudice against the basic, and in favour of the acid, metal has entirely disappeared. No distinction is now made between them, and it is presumed of a low-carbon steel that it was made by the basic process.

Whether the open-hearth or the converter metal is the better depends essentially upon the original material. When this is so uniform in composition that it can be blown with great certainty as to the result—as, for instance, at Peine—the best commercial irons can be produced from the converter, and even iron for horseshoe-nails not inferior to the Swedish. If the open-hearth furnace is generally preferred for specially high grades of product, this is only because it is easier, in the open-hearth furnace, to produce a uniform product from heterogeneous materials, and particularly to avoid in high-carbon metal an irregular distribution of the manganese.

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* The American Institute of Mining Engineers.

In the casting of ingot iron there has been no noteworthy change of the old methods. Funnels or sprues are often used, which deliver right and left, &c.; ingots are cast from the bottom or the top, with or without covering, in all of which, so far as I know, there is nothing new.

Attempts to compress the ingot metal, *i.e.*, to cause a better distribution of blow-holes, whether by mechanical pressure, or, according to Krupp's method, by means of carbonic acid, have proved less effective in improving the product than has the increased care which has been taken to secure a uniform chemical composition, and, above all, a precisely adjusted temperature, determined by experience for each class of metal, so that it shall be poured neither too hot nor too cold.

Among the many mechanical devices for giving the desired form to the metal, allusion will here be made to a few machines specially applied to the treatment of ingot metal.

In the arrangement of rolling-mills, it has been earnestly sought to develop the old-fashioned crude trains into carefully constructed machines, the gearing of which should not rattle loosely, but transmit power without loss, while the rolls should be placed with fine accuracy, and the pieces to be rolled should be automatically moved back and forward in the precise predetermined position. In the latter respect, the rolling-mill of the Phœnixhütte, shown in Fig. 49 (Plate XXX.), may be adduced as a good model. Here the liquid pig from the blast-furnace is transformed into ingot iron in the converter, recarbonised, and cast into ingots. These are annealed in Gjers soaking-pits, then removed by an automatic lever, and delivered to a train of live rollers, which carries them to the blooming-mill, from which they pass to the bloom-shears and to the rolls without having required, since the metal left the furnace, a single kilogramme of coal to be used upon them.

Where room is lacking in the rolling-mill—which is very often the case in the older establishments, since the requirements as to the length of rolled pieces have been steadily advancing —feed-roller trains are used, which incline upwards and often

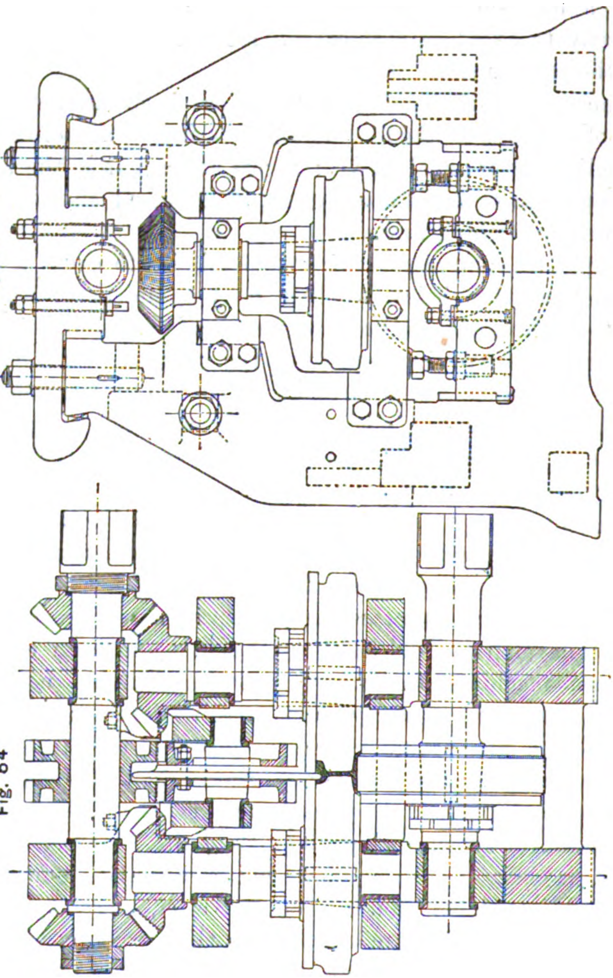


Fig. 55

Fig. 54

Finishing-Rolls for Grooved Rails.

extend above the roof (as at Oberhausen and Phœnixhütte). The space below is thus saved for other uses.

Street railways have been very widely introduced in Germany. The ingot metal rails are often rolled solid, receiving the necessary groove only in the last pass, as shown in Figs. 54, 55.

In the manufacture of wire, the most important improvement, doubtless, has been the automatic guides (*Umführungen*), which have increased not only the product of the works, but also the safety of the workmen.

Mannesmann Tube-Rolling.—The invention of the brothers Mannesmann, in the manufacture of pipes, may with good reason be regarded as an important improvement. For pipes destined to meet severe requirements of resistance to interior pressure, this system is calculated to revolutionise previous practice. I shall therefore attempt to describe it.

The process consists in feeding a solid, highly-heated round bar of ingot metal between rolls which, while their axes are oblique to the axis of revolution, both revolve *in the same direction.* The metal of the surface of the bar thus requires an increased motion in a spiral direction, and is drawn over its core, receiving, consequently, the form of a pipe. It is, indeed, not practicable, without an excessive expenditure of power, to make the interior diameter of such a pipe very large. But it is sufficient that an interior space is created, for there is no difficulty in widening it over a mandril by further operations between rolls in the form of conical discs, revolving in opposite directions. Since, in this operation also, the pipe moves spirally forward, and all its parts are spirally pushed and pressed, the metal becomes still denser. It is this spiral arrangement of material which makes the Mannesmann pipes so remarkable, quite apart from the advantage they possess in presenting no lines of welding whatever. Moreover, blow-holes (which are *invariably* present in ingot iron) are so squeezed out spirally as to make the walls of the pipe completely impermeable. A proof of this is the retention of hydrogen for weeks in a piece of Mannesmann pipe, closed at both ends. Pipes thus made and enlarged have been successfully produced of all diameters up to 400 mm.

The Mannesmann rolls have to be driven at a speed of 300 revolutions and upwards, and their relative positions to each other and to the driving-shaft must be made adjustable with the nicest precision through a wide angle. These severe requirements in coupling the rolls to the driving-shaft have been met by a special design indicated in Fig. 56. Two shafts, *a* and *b*, are each provided, at points equally distant from the centre *S*, with two arms that form equal angles with *aS* and *bS*, and constitute couples which will remain in constant contact. The touching points s_1 and s_2 slide towards and away from the centre *S*, each describing an ellipse during a complete revolution. In practice, this movement is accomplished by setting a bronze semi-cylinder *a′* into a rounded groove on each driving-arm, and making it bear with its flat surface upon a similar semi-cylinder, *b′*, which is fitted into the corresponding driven arm. The device is ingenious, and works well.

Fig. 56.

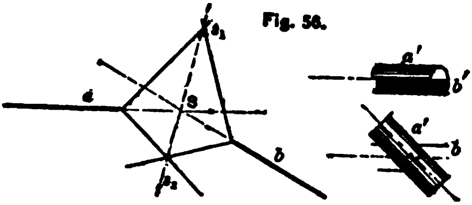


Diagram of Mannesmann's Universal Joint.

Another serious obstacle, which had to be overcome by special design, lay in the excessive unit-stresses in the teeth of common gearing when transmitting very high powers at high rates of speed. The form of the new Mannesmann gearing is indicated in Fig. 57. The teeth or pins are shown at *a′ b′*; they are so shaped that one seizes the other like a fork. It is evident that when both wheels have the same number of teeth, and when their axes are parallel to each other, the forks and the blades must meet accurately, provided the teeth be always kept in a parallel position. In both wheels this parallelism of the teeth throughout their movement is maintained by special appliances not shown. But the position of the axes of the two wheels may be swung at any angle, provided the line *A A*, Fig. 57, remains

Fig. 57.

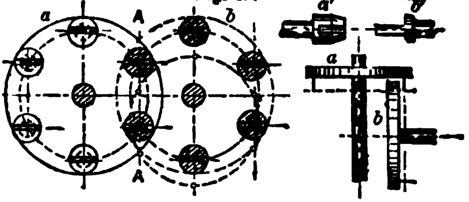


Diagram of Mannesmann's Universal Gearing for Heavy Power Transmission.

vertical. In that manner a right-angle transmission, sketched at the right side of Fig. 57, may be obtained, and a large contact surface still be preserved for the transmission of pressure.

A further necessity for this process was the required storage of power, for which the fly-wheel of ordinary construction was not sufficient. This object was attained by making fly-wheels with a rim of *wire* to run very rapidly.

Fig. 58

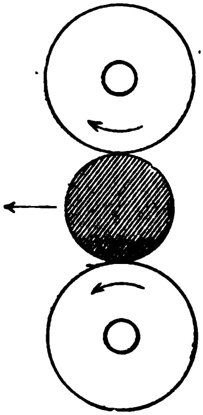


Fig. 60

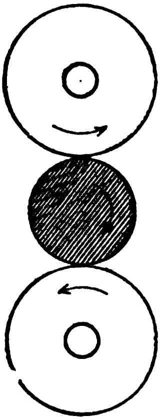


Fig. 59

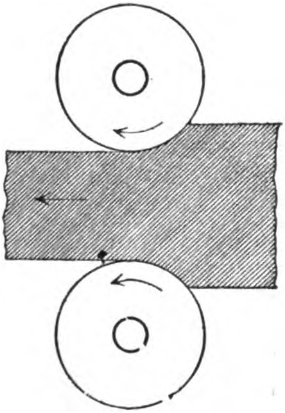
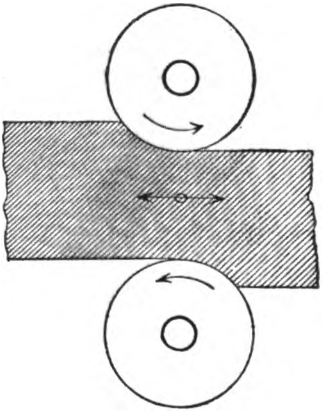


Fig. 61



Diagrams showing the Action of Parallel Rolls.

The formation of pipes by the Mannesmann rolls is indicated by the diagrams, Figs. 58 to 68. Figs. 58 and 59 show the ordinary rolling process with parallel roll-axes and opposite directions of revolution; Figs. 60 and 61, the same, when the rolls revolve in the same direction. In Figs. 62 and 63 is shown the effect of obliquely set rolls, operating by simple friction. Figs. 64 and 65 show the formation of pipes, under similar circumstances, but with the added effect of pressure, *i.e.*, the squeezing forward of the several particles of metal. Figs. 66 to 68 illustrate the enlargement over a mandril by means of conical obliquely set rolls. Figs. 69, 70, and 71 show the latest arrangement in actual practice.

Fig. 62

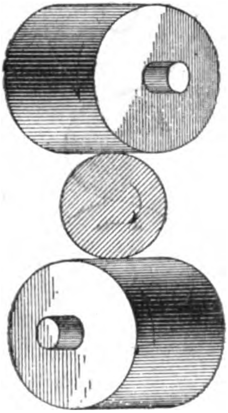
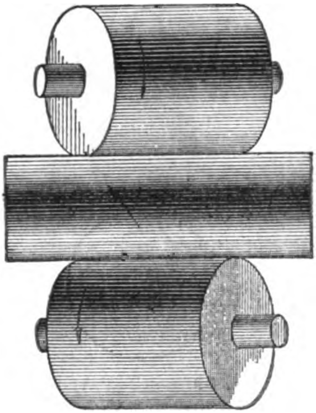
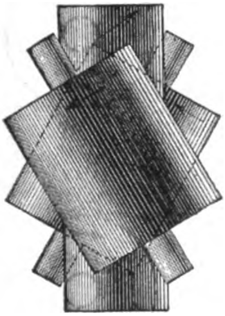


Fig. 63





Diagrams Illustrating Mannesmann's Process for Rolling Tubes.

V.—Chemical, Mechanical, and Microscopic Investigations of Iron.

The progress of the metallurgy of iron in Germany has only been practicable with the help of science. Chemistry, physics, and mechanics have furnished the foundations for its successive improvements. Sometimes new processes or devices have been directly deduced from the results of scientific inquiry; sometimes it has been the function of science to seek the principles underlying practical improvements, and thus to render their further development possible. There are consequently many novelties worthy of mention in the mechanical as well as the chemical

Fig. 64

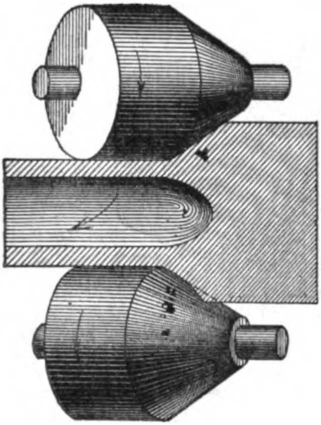
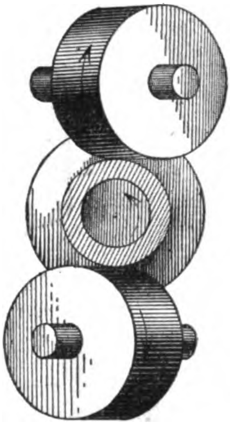
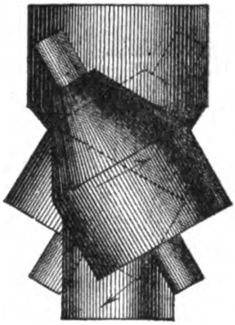


Fig. 65





Diagrams Illustrating Mannesmann's Process for Rolling Tubes.

investigation of iron. With regard to testing-machines, more perfect apparatus for measuring strains has been a desideratum. To the perfection of such mechanism American example has contributed not a little; and the principles of Mr. Emery's machine, in the Watertown Arsenal, have received full recognition. Above all, the earnest tendency, departing from former rules, is not to draw conclusions from single results, perhaps of a purely accidental character, but to make observations systematically, in series, and upon as many samples as possible, for the elimination of accidental errors; and also to establish the most suitable method of testing, so that, even if errors be involved, they need not vitiate comparisons where the same methods have been employed.

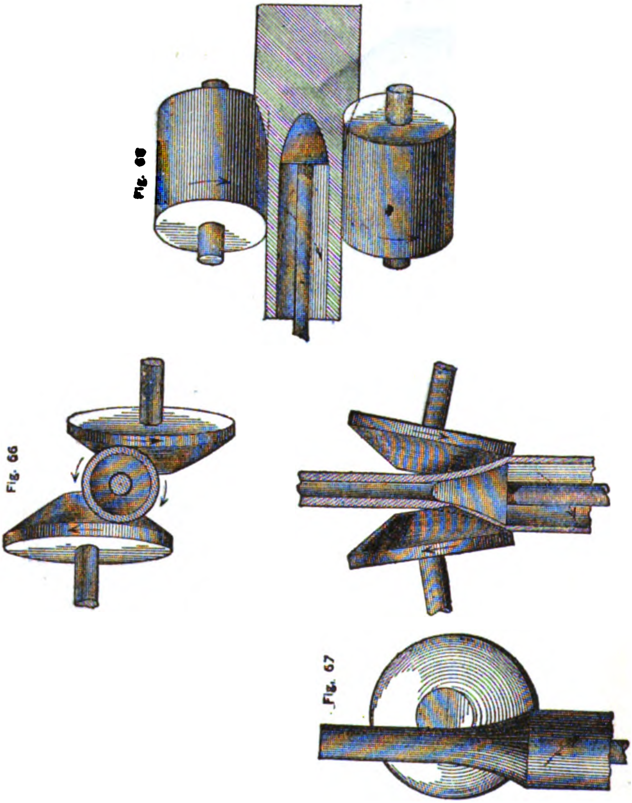


Fig. 65

Fig. 66

Fig. 67

Diagrams Illustrating Mannesmann's Process for Rolling Tubes.

The latter tendency may be asserted likewise for the special

Fig. 69.

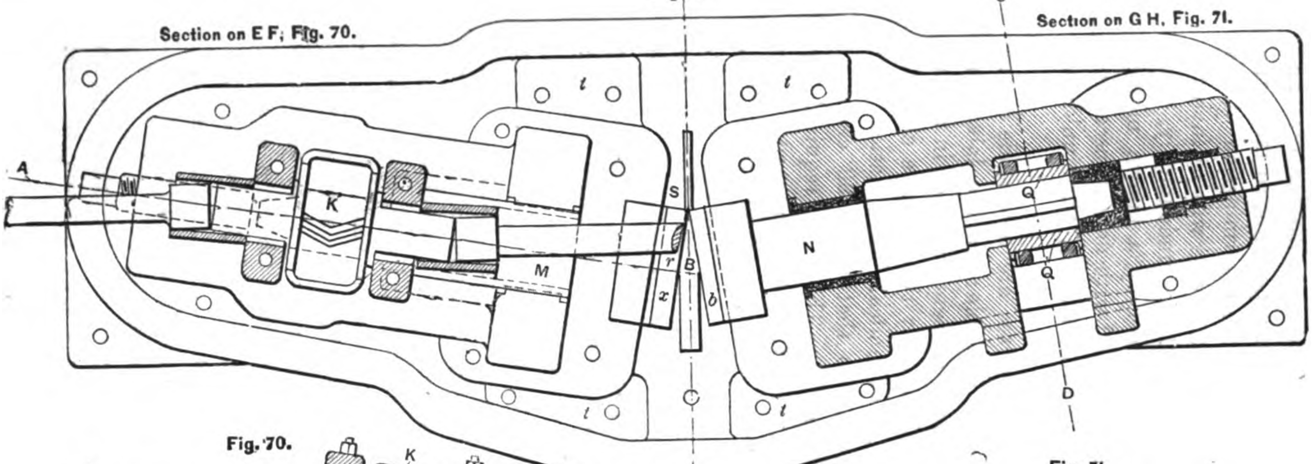


Fig. 70.

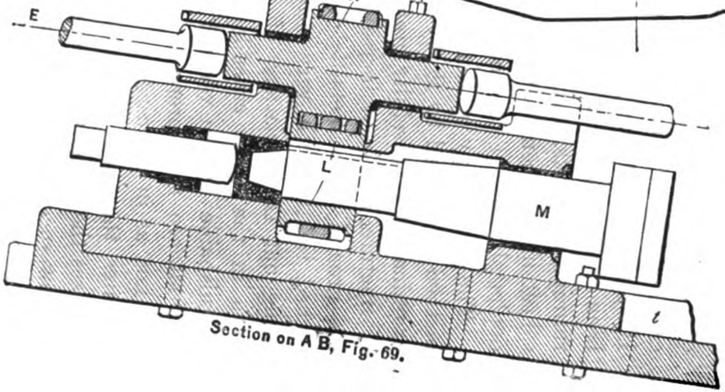
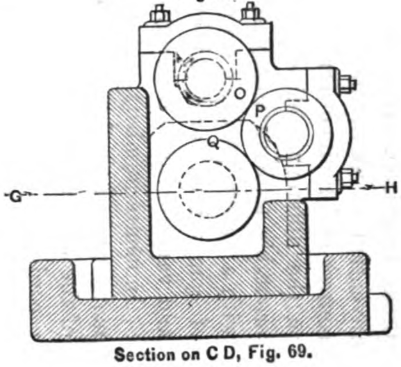


Fig. 71.



Latest Arrangement of Mannesmann Tube-Rolling Mill.

branch of analytical chemistry which deals with the ores and products of iron. Here, also, we have to report, not so much the invention of wholly new methods, as the determination of the sources and limits of error, which are and always will be involved in the different methods employed. It is, undoubtedly, more profitable to have steady results obtained by a known method with a known probable error, than to deal with data insusceptible of comparison, furnished by unknown methods, with unknown and variable limits of error.

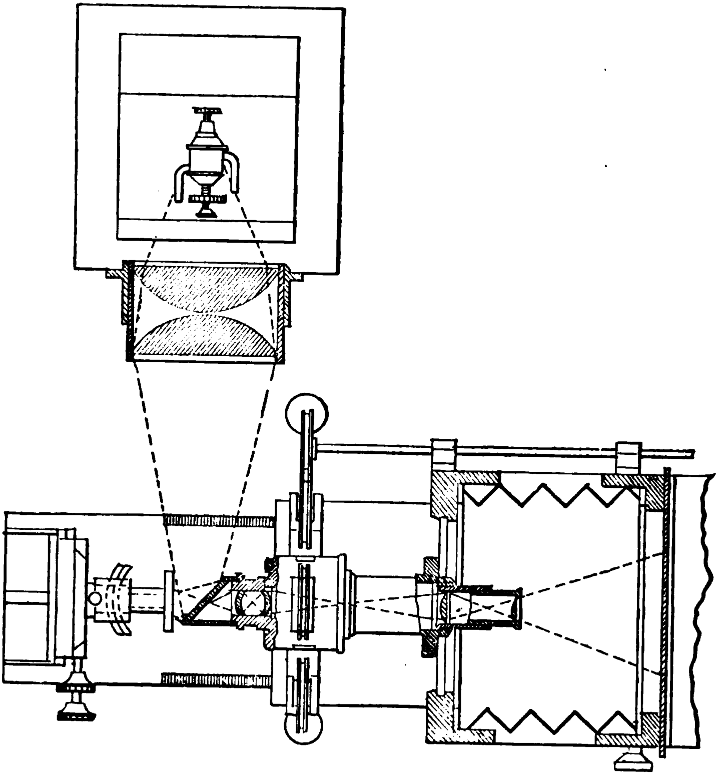
Immense numbers of tests and analyses are now made at our metallurgical works. To take an example: In the laboratory of the Rothe Erde Works, near Aachen, there are made in a year, according to the statement of Kintzlé, by two to three chemists and six to seven assistants, 26,500 chemical determinations, and 62,000 bending and tensile tests; so that about 90 chemical determinations must be made daily. The time required for chemical operations has been proportionally shortened. The different elements can now be determined in the following periods, expressed in minutes: Phosphorus, 30; carbon, 30; manganese, 100; silicon, 60; sulphur (cadmium method), 30. Thus it has been made practicable to maintain a continuous control of the running of works, and even, for instance, to wait before tapping a heat in the open-hearth furnace, until its sufficiently complete dephosphorisation has been chemically ascertained.

The microscopy of iron is constantly widening its field. The method discovered by Sorby nearly thirty years ago, namely, the examination of carefully ground sections, instead of the surfaces of fracture, has been increasingly employed. Samples of metal are ground upon metallic discs, carefully polished, cleaned, and etched lightly with very dilute hydrochloric acid, in order to bring out the variations of texture which are always present, even in the finest crucible cast steel, and which are made distinguishable by the varying depth to which they are attacked. The surface thus prepared is treated to 210° C. (provided this will not, as in the case of hardened steel, affect its texture), and acquires thereby a variety of colouring which still further emphasises the various elements in its composition.

How successfully, in this way, characteristic features of grades of iron can be discovered, comparisons can be made, physical differences coexisting with identity of chemical constitution can be explained, and the true grounds of many disasters can be demonstrated, whether in the fault of the material or in the excessive strain to which it was subjected, many series of experiments have already proved.

The aid of photography has been invoked to make the results obtained by single observers the property of all. In photographing sections prepared as above described, only ortho-chromatic plates can be used. A further difficulty—namely, that to get a true photograph, the illumination of the section should be perpendicular to its surface, while at the same time the section must be placed perpendicular to the axis of the microscope, through

Fig. 72.



Apparatus for Perpendicular Illumination in Micro-Photography.

which it is photographed—has been overcome by the use of a parallel plane glass plate, which serves also as a mirror. Fig. 72 is an illustration of a convenient apparatus now used for this purpose.

The thirty slides exhibited in connection with the reading of this paper * give a general view of the characteristics detected by the microscope in the different kinds of iron. These illustrations may furnish a good starting-point and guide to those who desire to make similar investigations for the benefit of their own works.

In conclusion, I may be permitted to say that the outlook for our German iron and steel industries is neither all brightness nor all shadow. On the one hand, the patent-law of 1877 and the tariff-law of 1879 have greatly stimulated industrial activity and technical progress in this business, and the basic process, coming just at the right time, has made us independent of other countries for our raw material. On the other hand, the severity of military duty, both withdrawing and estranging from labour for three years every strong and healthy workman, and the compulsory contributions required by law from employers for the insurance (life and accident), medical care, and pensioning of *employés*, constitute patriotic and philanthropic burdens, which we must needs feel in competition with other countries not similarly handicapped. But the ironmasters of Germany make no complaint. On the contrary, spurred rather than daunted by difficulties, they mean, by increased vigilance, energy, economy, technical skill, and continuous scientific researches, to maintain the honourable rank of the German Empire among the iron and steel producing nations of the world.

DISCUSSION.

Professor LUNGE, Zurich: I beg to point out that the Mannesmann tubes, of which there is such a beautiful exhibit in illustration of Prof. Wedding's paper, are likely to be of the greatest importance for chemical manufacturing, and that in two different directions.

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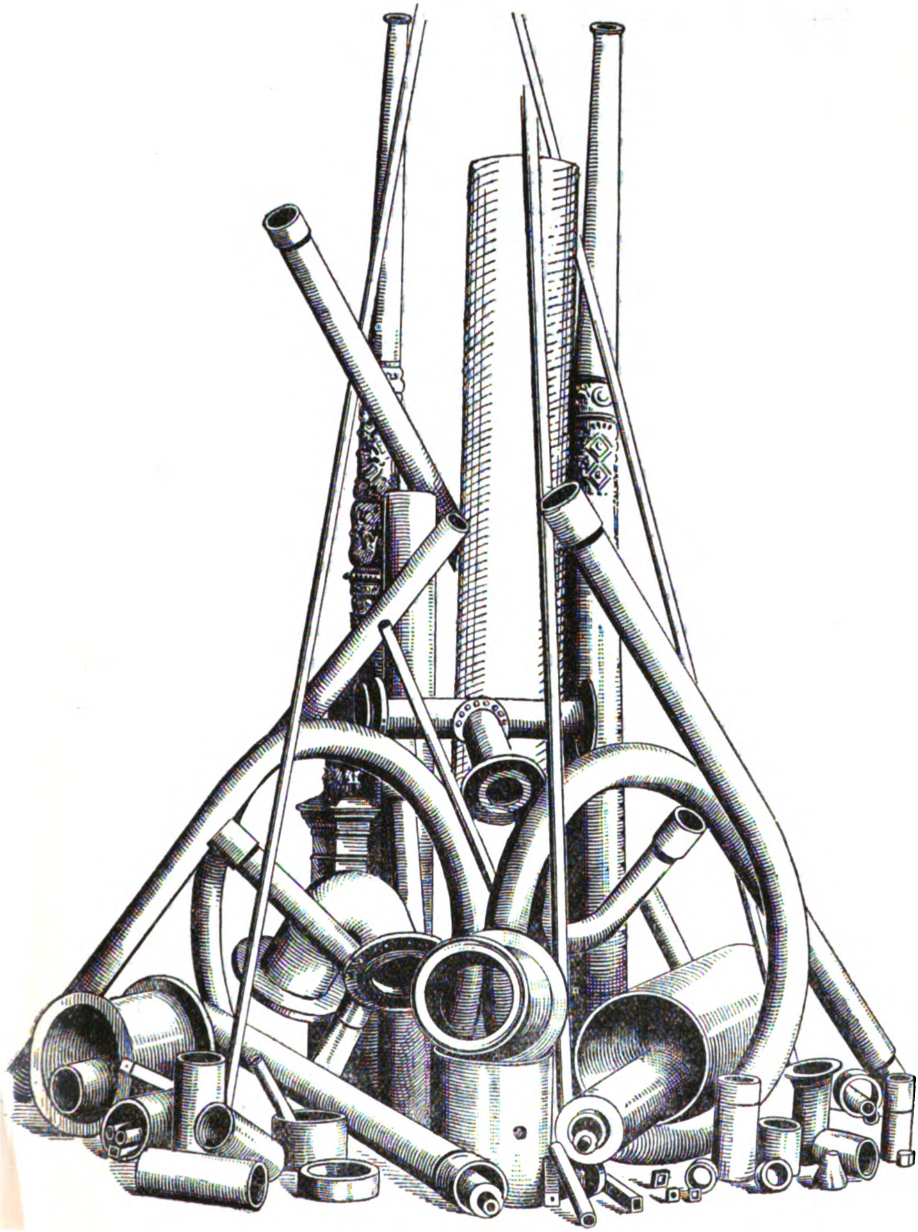
* Photographs of these slides, bound in a handsome album, have been presented to the Institute by Professor Wedding.

Fig. 73.



Mannesmann Tubes and Tube Products.

In the first place, they seem to supply the best possible material for making high-pressure vessels for storing and carrying liquid carbon dioxide, ammonia, sulphur dioxide, chlorine, and compressed oxygen, and for all similar purposes. Hitherto the dead weight of the iron flasks required for such purposes has been a serious drawback, since it amounts to several times the weight of the contained liquefied or compressed gas—a circumstance which has been absolutely prohibitory in many cases, in which consumers would gladly have availed themselves of the great convenience offered by the commercial supply of such substances in desired quantity on demand. As the Mannesmann tubes are very much stronger than ordinary wrought iron or steel tubes of the same weight, they can be made correspondingly lighter; and when it is considered that they are already supplied up to 15 inches in diameter, and capable of resisting at that diameter a pressure of several hundred atmospheres, it is not necessary to dwell on the importance of this improvement.

In the second place, the Mannesmann tubes offer the possibility of carrying out chemical reactions under high pressures at a fraction of the expense which has now to be incurred for such purposes. The manufacture of dimethyl aniline among organic compounds, and of sulphur trioxide among inorganic substances, are instances I could cite in this direction. Altogether I feel bound to welcome this ingenious Mannesmann tube-rolling process as a precious addition to the resources of the chemical manufacturer.

At the close of the reading and discussion of Professor Wedding's paper a variety of Mannesmann tubes and tube products, furnished by the German-Austrian Mannesmann Tube Works of Berlin, from its mills at Remscheid, Komatou, and Bous, and by the Mannesmann Tube Co. of Landore (South Wales), was exhibited, and was afterwards presented to the museum of the Engineers' Society of Western Pennsylvania, the present being suitably acknowledged by Professor J. W. Langley. [Fig. 73 is a view of this exhibit in part.]

The **Chairman** suggested that any discussion which might follow should be carried on in writing. He then requested Dr. Raymond to make some few observations as to the Mannesmann process, in so far as it illustrated Dr. Wedding's paper.

Dr. **Raymond** said that this very interesting process, which was already known to them in America through the technical journals, and which had been described in its essential outlines in Dr. Wedding's paper, had been illustrated so magnificently, at such expense and trouble, by the Mannesmanns, through that splendid exhibition of seamless steel pipes, that he felt desirous of saying simply one word, namely, that Mr. Mannesmann had already printed an explanation and account of the samples that they saw exhibited there, and which he thought would well reward the time of any gentleman who wished to examine them after the session had concluded.

Mr. H. M. **Howe**, Vice-President of the American Institute of Mining Engineers, here took the chair, while Mr. Thielen read his paper.

ON THE DARBY PROCESS OF RECARBURISATION.

By Mr. A. THIELEN, Managing Director of the Phœnix Steelworks at Ruhrort, Rhenish Prussia.

In experiments for the production of steel, the chief point in the solution of the problem is always the introduction into or the removal from the iron of a determinate quantity of carbon.

Although in the past the solution of this problem was attacked more or less unconsciously and empyrically, yet, with the development of analytical chemistry, the *rôle* which carbon plays in the constitution of steel was soon made clear in all its significance, and thereby a large part of the problems met with by the steelmaker were more clearly defined than before.

For a long time, and even to-day, to a certain extent, the percentage of carbon in steel is the chief point for determining the quality and the grade of hardness.

In many cases, the percentage of carbon was alone relied on for the judging of large consignments; for example, the large deliveries of wire billets and blooms to America during the last twenty years, and even to-day, when the influence of the other constituents is recognised, when many other considerations have to be taken into account, and when, as it appears, some special steels can more or less do without the assistance of carbon—such as the Hadfield manganese steel—yet for our Bessemer, basic, Siemens, and crucible steel the carbon remains still, as formerly, one of the most important constituents, and, we venture to say, is indispensable.

As is widely known, in order to produce in the converter, by means of Sir Henry Bessemer's great invention, steel of a wished-for percentage of carbon, two methods present themselves. By the one, the process is stopped when the bath possesses the desired content of carbon; by the other, the bath is completely decarburised, and then the wished-for carbon added in the form of spiegel, ferro-manganese, &c. In Germany the latter method only came into use, and was retained, when the Thomas-Gilchrist process for the production of steel low in phosphorus from highly phosphoric iron in the basic converter came successfully into use; the more so as, from the nature of the process, before dephosphorisation takes place complete decarburisation is necessary. But while, by the old acid process, the carburisation readily takes place by the simple addition of spiegeleisen, &c., the new process brought with it difficulties not easy to be overcome, inasmuch as the oxides which are always present in the basic process to a larger or smaller extent, and also the phosphoric acid of the slag, take part in the reaction. Even if one succeeded in removing part of the oxide by pouring off the slag and regulating the amount left dissolved in the bath by so perfecting the process that there would be approximately an equal amount remaining in each charge, and even if the danger of rephosphorisation were diminished by as complete a removal of the slag as possible, and by suitable slag additions made to the still remaining slag, still the production of low phosphorus steel, high in carbon, could not be accomplished so readily as not to make the introduction of another simple method of carburising well worth wishing for. The circumstances are similar as regards the basic and acid open-hearth processes.

It can readily be understood, therefore, why, after the introduction of the method of making steel in basic-lined vessels, proposals which had been formerly made for the introduction of carbon otherwise than by the indirect way, by means of spiegel, &c., but which had hitherto remained without results, should be brought forward again from various quarters. All of these processes were based on the known fact of the great affinity between carbon and iron at high heats. It was sought to reduce and carburise the bath of steel by the introduction of carburetted gases, by the addition of tar, petroleum, &c., as well as by many mixtures of these substances with solid bodies, such as burnt dolomite. However, the result of all these experiments did not lead to the permanent introduction of any of them in practical work until Mr. John Henry Darby, the managing director of the Brymbo Steelworks, succeeded in finding a solution of the problem.

Having attentively remarked an increase of carbon that took place in two pieces which had been treated in the coal fire for welding, he brought fluid steel into intimate contact with solid carbon, the result being a rapid absorption of the carbon by the steel. Supported by this experiment, he founded on it his patented process by which fluid steel can be carburised by filtration through pieces of carbon, preferably in the form of graphite or wood charcoal, &c. He employed for this purpose the apparatus shown in Fig. 1.

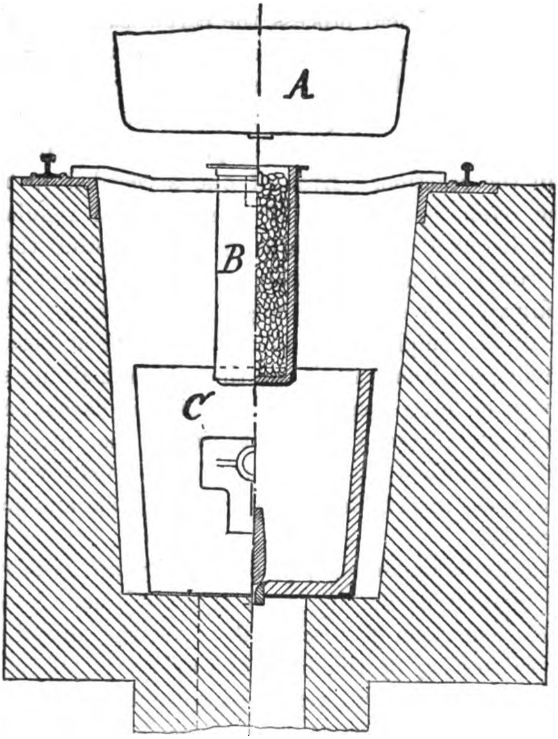


Fig. 1.

This consists of a sheet-iron cylinder, *B*, open at the top, and closed at the bottom by a plate pierced with numerous holes, the whole being lined with refractory material. It is filled with the carbonaceous material, and inserted either between the two steel ladles *A* and *C*, or between the Siemens furnace and the steel ladle. The fluid steel takes its way through the interstices of the pieces of carbon, and is thereby brought, by absorption of the carbon, to the wished-for percentage of carbon.

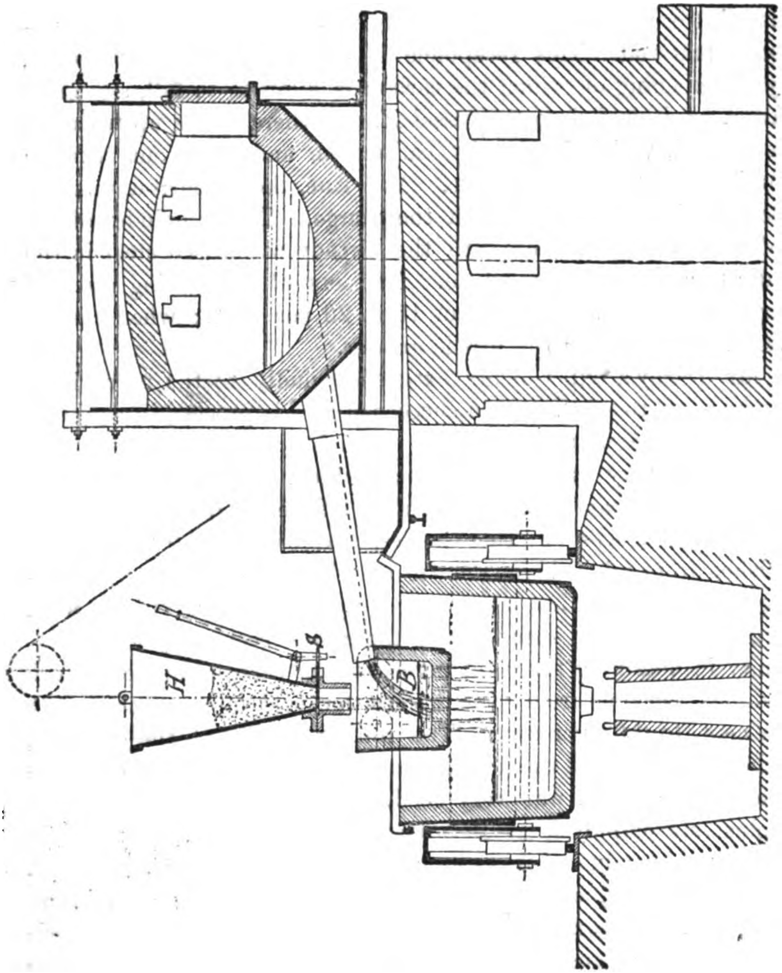


Fig. 2

Further experiments showed that the absorption of the carbon was so rapid as to make the long time of contact, which the above-described filtration gave, unnecessary. Mr. Darby therefore constructed the apparatus shown in Fig. 2.

In this, the cylindrical filter is replaced by the vessel *B*, which is conveniently supported between the open-hearth furnace and the steel ladle, or between two other steel ladles. It is, like the filter, also lined with refractory material, and is furnished with a perforated refractory bottom plate. Above this vessel is placed the receptacle *H*, containing the roughly broken carbonaceous material. This receptacle is closed by a slide-valve, *S*, by the opening of which the carbon is allowed to fall, slower or faster, as desired, into the vessel *K*, and there mixes up with the fluid steel, which is thereby carburised, and flows out through the holes in the bottom plate. As a rule, the carburisation takes place during the first third of the charge. The remainder of the soft steel then mixes up with the already carburised steel in the ladle to a homogeneous whole. The loss of carburising material (graphite) by burning is about 15 to 20 per cent.; when coke is used for carburising the loss is greater.

Mr. Darby's experiments extended wholly to the carburising of open-hearth steel, and he succeeded by his process, in conjunction with the basic process, in producing from phosphoric raw material a very excellent product, which, with any wished-for percentage of carbon to upwards of 0·9 per cent., contains only very small traces of other bodies, and consequently is distinguished from all hitherto known open-hearth steel by its exceeding toughness. It has been worked up into chisels, knives, wire, &c., with the best results, and there has been very great certainty in obtaining the right percentage of carbon, the percentage obtained varying from that wished for seldom more than 0·01 per cent. to 0·02 per cent. The rolling quality of the material, although only very small additions of ferro-manganese or ferro-silicon were made, was very good. The process was very soon exclusively employed at Brymbo for the harder steels; but in order to introduce his system to the Bessemer process, Mr. Darby, in 1889, entered into an agreement with the Phœnix Company, of Laar, near Ruhrort, on the Rhine. The experiments were arranged in the basic Bessemer works with the apparatus described in Fig. 2, to which the arrangement represented in Fig. 3 was given. The carburising vessel *B* was arranged between the two ladles *A* and *C*, standing one over the other, and the steel was carburised whilst streaming from the first into the second ladle by the stream of carbonaceous materia issuing from *H*, regulated by the valve-handle *D*. It quickly appeared, however, that the basic Bessemer steel, although readily carburised, yet thereby lost its rolling qualities to such an extent that the ingots fell to pieces in the rolls. On inquiring into the cause of this, it was discovered to be due to the method of carrying out the process, viz., that for four minutes more than sixty fine streams of steel were oxidised by means of the atmospheric oxygen. It was sought to overcome this drawback by replacing the sixty holes in the bottom of the vessel by one of suitable diameter. A considerable improvement in the rolling quality of the ingots was thereby produced. But the rolling quality attained was not equal to that of the ordinary basic ingots, and the apparatus was on this account superseded by the arrangement shown in Figs. 4 and 6. The carburising vessel was here replaced by the refractory lined funnel *B*, open at the bottom, which was arranged between the casting-ladle and the moulds. By an arrangement attached to the side

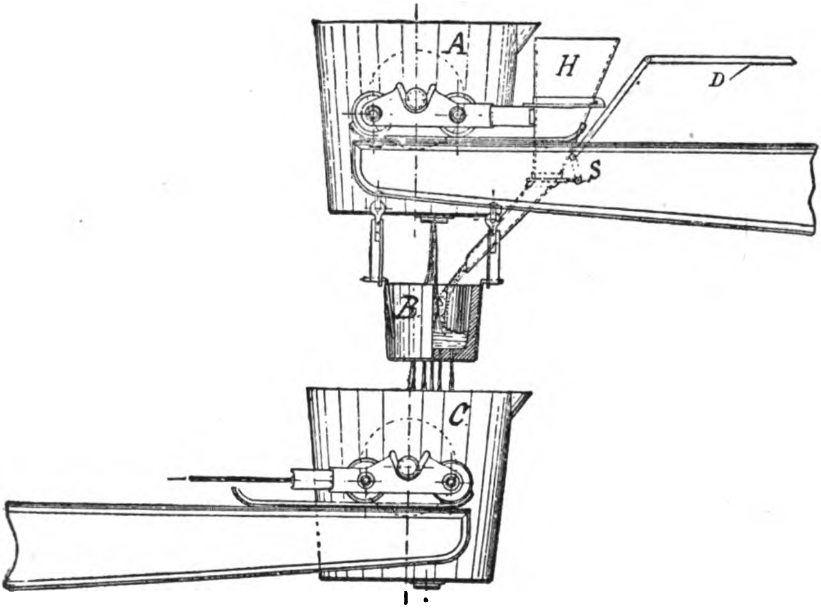


Fig. 3.

of the casting-crane it was possible to introduce into the funnel *B* the ground carbonaceous material, little by little, in a well-regulated stream. This arrangement consists of an accurately bored cylinder, *E*, provided with a lathe-cut worm, the receptacle *H*, and the turning arrangement *G*. As is readily apparent, the amount of carbonaceous material forced out is proportional to the number of rotations which the endless screw makes, which can be accurately regulated. By the employment of this apparatus the carburising is safely done in the wished-for manner, and good rolling ingots obtained. The ground coke appeared to be more quickly absorbed than the graphite, so that the whole of the experiments were carried out with this material. It was found that with ingots weighing 1400 kilos, and measuring 16 inches square, the carbon was very equally distributed throughout,

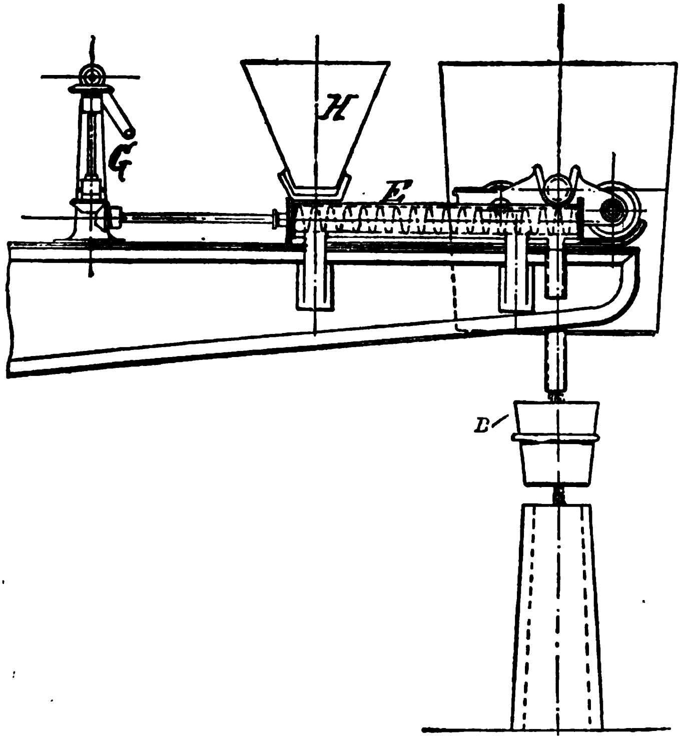


Fig. 4.

With some attention, the frequently occurring increase of carbon in the top parts of ingots of this weight was successfully overcome by a lessened addition of carbon to the upper part. In order to test the equal distribution of the carbon, ingots were rolled down into 2-inch billets, and tests were taken from the two ends and the middle of the same.

Fig. 5 shows a second arrangement for carrying out this process. The carbonaceous material flows from the holder *H* into the fan-wheel *E*. By turning the wheel by means of the winch *G*, the filled compartments empty themselves and allow the carbonaceous matter to flow in regulated quantity into the vessel *B*. The results obtained from the trial of this apparatus are given in Table I.

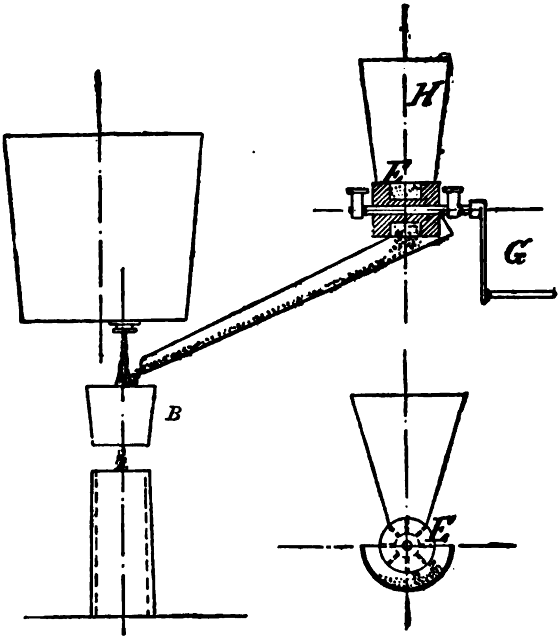


Fig 5.

Although this method of carrying out the process offered considerable advantages over the earlier way, yet it brought this disadvantage with it, that the accuracy and amount of the carburisation was essentially dependent on the workman's rate of rotation of the endless screw. To effect the rotation by mechanical means appeared impracticable, because it must continually be brought into accord with the speed of the stream of molten steel, which varied according to the temperature and condition of the stopper-hole. The observation that the carbonaceous material, finely ground coke, is immediately absorbed at the first contact with the molten steel led to an arrangement by which this latter drawback was obviated. By the arrangement shown in Fig. 6 the carbonaceous material could be added direct to the stream of molten steel flowing from the converter before it reached the ladle *C*, whilst the slag could be retained in the converter until the carburisation was complete, by means of a suitable plate, *F*, lined with refractory material, or by a block of refractory material.

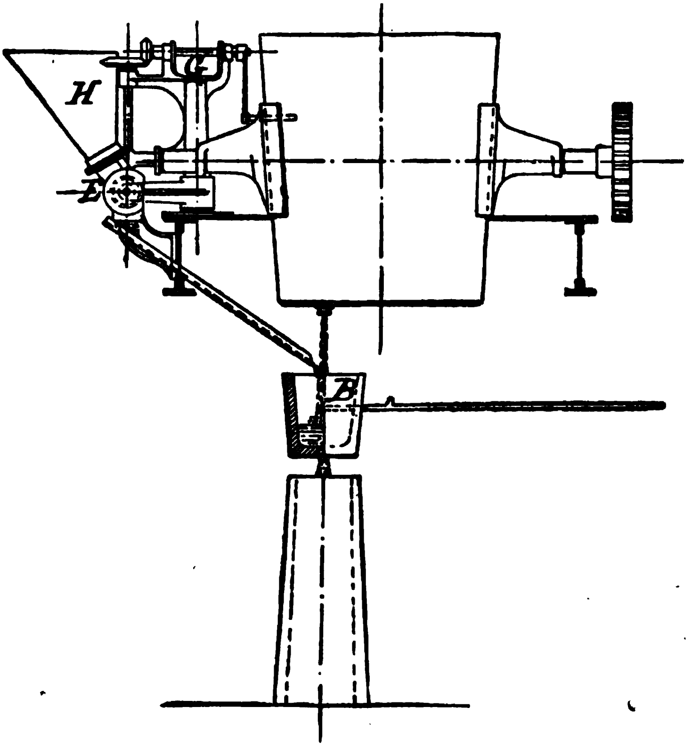


Fig. 6.

The quantity of the carbonaceous material flowing out from the receiver *H* is, as before, regulated by means of the slide-valve *D*. Some of the results obtained by this method are given in Table II. In this way there was produced at the said works, during the month of June, 70 per cent. of the rail-steel charges, also a number of charges for hard and welding basic steel, the whole of which gave satisfactory results. It may be remarked that, with the carburising system, in the basic process the same addition of ferro-manganese is required as for soft ingot charges, or as is necessary for the production of hard sorts of steel with spiegeleisen.

After a series of very successful results had been obtained in this simple way, the process was employed also in the open-hearth and ordinary Bessemer practice. As was to be expected, the results obtained were so favourable that the employment of the carburising vessel has now been discontinued in these works.

Collecting now, in conclusion, the advantages which this carburising process offers in each of the methods for the production of steel, we find:—

1. In the basic Bessemer or Thomas process the carburising takes place in the almost complete absence of a slag rich in oxides and phosphoric acid; consequently it proceeds with certainty, it is accompanied by no important rephosphorisation, and it is practicable for any desired percentage, without simultaneously increasing the manganese. By the omission of the spiegeleisen a considerable economy is effected.

2. In the acid Bessemer process the carburisation takes place up to the highest grade of hardness with far greater safety than by the help of spiegel, and without the increase in manganese consequent upon the employment of the latter process. Here also a considerable economy is effected, due to the saving in spiegel. The trials were made, amongst others, in some American works.

3. In the open-hearth process, for the acid and basic open-hearth processes, the advantages obtained are very nearly identical with those mentioned for the Bessemer and Thomas processes, the very considerable cost of the ferro-manganese and ferro-silicon especially wholly or for the greater part avoided. The combination of the process with the basic open-hearth process permits of the production of a steel which, for many industrial purposes, can successfully measure itself with crucible steel. By this

method, also, a material is produced which in the future will find

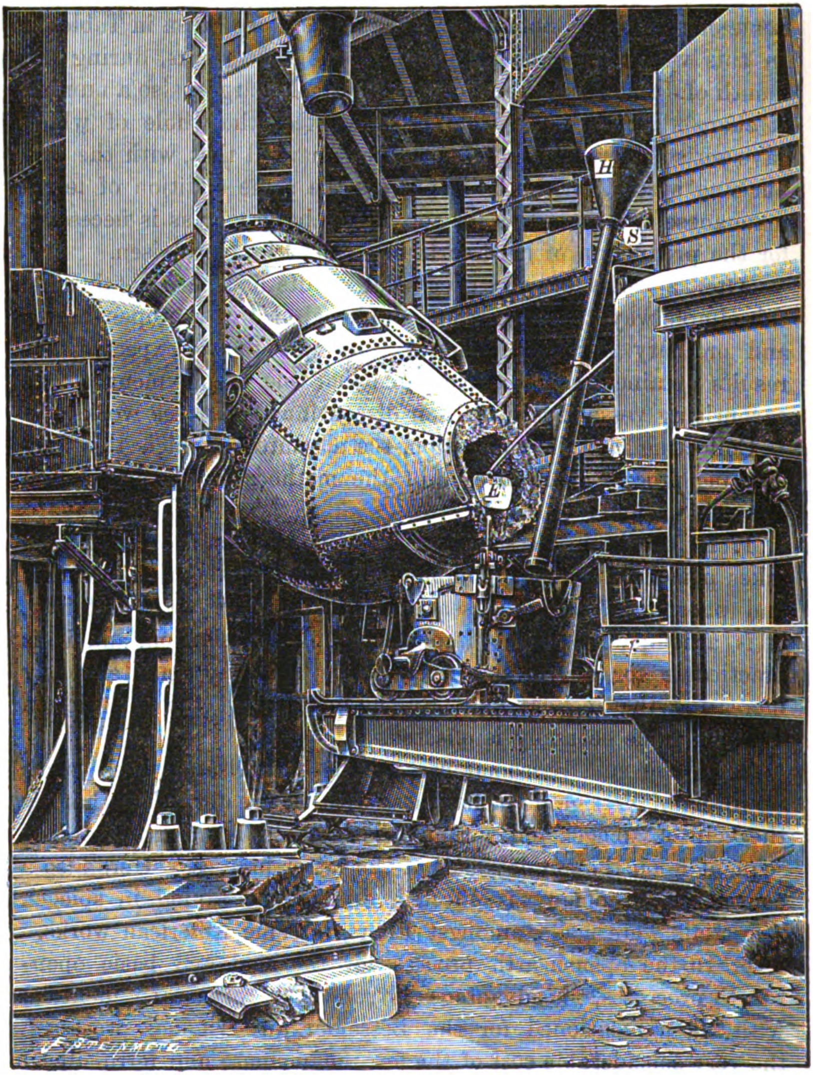


Fig. 7.

very advantageous employment as the raw material in the crucible steel process.

For example, for the production, in the basic converter, of a rail steel of 50 kgs. per sq. mm. tensile strength, there is required for a charge of from 9 to 9·5 tons output:—

(*a*) By the employment of the ordinary process:—

Spiegeleisen 10–12 per cent.	600 kgs.
Ferro-manganese 60–65 per cent.	80 „

(*b*) By the employment of the carburising process:—

Spiegeleisen	nil.
Ferro-manganese 60–65 per cent.	80 kgs.
Coke	60 „

For the acid process, the calculation also shows itself in favour of the carburising process.

If steel of similar hardness is to be produced in the basic open-hearth furnace, there is required for a charge of ten tons:—

(*a*) By the employment of the ordinary process:—

Spiegeleisen 10–12 per cent.	250 kgs.
Ferro-manganese 60–65 per cent.	80 „

(*b*) By the employment of the carburising process:—

Spiegeleisen	nil.
Ferro-manganese	12 kgs. or less
Coke	50 „

The economy resulting from the employment of the carburising process is here considerable; a similar relation holds good in the acid open-hearth process. From the foregoing it is clear that the superiority of the carburising process in regard to the question of cost becomes the more considerable the higher the grade of hardness of the material to be produced, to the advantage that the harder sorts of steel can be produced with far greater ease and safety. There is to be added the very considerable economy in the cost of production, while by the old process the cost of production rose considerably with the grade of hardness.

During the month of July there was effected in the carburising process another modification which considerably improved one of our leading articles, viz., tyres. We use, for the manufacture of tyres, small ingots, containing sufficient material for one tyre, which, after being hammered into flat discs, are perforated in the middle, this perforation being enlarged before the disc is reheated before rolling. This method requires that the surface of the ingots is without any flaws, and it must be, as well, without any pores, as all these deficiencies can be seen afterwards in the finished tyres. The Siemens-Martin steel obtained by the carburisation process does not immediately after the casting show an absolutely even surface. The carburised material was, therefore, not taken as material for tyres.

Experiments were made to give the bath a small addition of aluminium, and in consequence of this all difficulties were removed. By adding at the outside 0·04 per cent. of aluminium an ingot was obtained which was absolutely free from porosities, and eminently fit to be used for tyres. Following up these experiments, several solid castings were made out of the carburised material, and these turned out equally satisfactory, being positively flawless.

TABLE I.—*Showing the Carbon in each Ingot, when Carbon was added to each Ingot.*

		Percentage of Carbon.	
		Desired.	Found.
Ingot I.	Section A.	0·25	0·255
„	„ B.		0·260
„	„ C.		0·251
Ingot II.	Section A.	0·25	0·244
„	„ B.		0·248
„	„ C.		0·254
Ingot III.	Section A.	0·30	0·285
„	„ B.		0·311
„	„ C.		0·306
Ingot IV.	Section A.	0·35	0·330
„	„ B.		0·324
„	„ C.		0·340
Ingot V.	Section A.	0·35	0·350
„	„ B.		0·357
„	„ C.		0·352
Ingot VI.	Section A.	0·45	0·461
„	„ B.		0·455
„	„ C.		0·470

TABLE II.—*Carburised Basic Bessemer (Thomas) Charges.*

Percentage of Carbon.		Percentage of Phosphorus.	
Before Carburisation.	After Carburisation.	Before Carburisation.	After Carburisation.
0·073	0·285 first ingot. 0·290 last "	0·040	0·040
0·070	0·268 first " 0·266 last "	0·052	0·070
0·082	0·293 first " 0·290 last "	0·045	0·054
0·078	0·301 first " 0·320 last "	0·038	0·046
0·080	0·274 first " 0·276 last "	0·049	0·049
0·091	0·315 first " 0·320 last "	0·074	0·085
0·083	0·298 first " 0·290 last "	0·063	0·072
0·095	0·274 first " 0·277 last "	0·048	0·049
0·072	0·284 first " 0·279 last "	0·055	0·067
0·083	0·269 first " 0·266 last "	0·042	0·050
0·089	0·300 first " 0·312 last "	0·044	0·056
0·077	0·323 first " 0·320 last "	0·073	0·075

TABLE III.—*Carburised Open-Hearth Charges.*

Desired per Cent. C.	Found before Carburising.	After Carburising.
0·51	0·075	0·51
0·60	0·072	0·592 first ingot 0·592 last "
0·65	0·069	0·668 first " 0·660 last "
0·7	0·076	0·708 first " 0·700 last "
0·8	0·070	0·804 first " 0·804 last "

TABLE IV.—*Carburised Acid Bessemer Charges.*

Desired.	Found.
0·30—0·32	0·30
0·28—0·30	0·27
0·28—0·30	0·32
0·36—0·42	0·37
,,	0·39
,,	0·42
,,	0·43
,,	0·42

(Made by Carnegie, Phipps, & Co.)

TABLE V.—*Carburised Acid Open-Hearth Charges.*

Desired.	Found.	
0·30—0·32	0·30	
0·28—0·30	0·27	
0·28—0·30	0·32	
0·36—0·42	0·37	
	0·39	
	0·42	
	0·43	
	0·42	
0·50	0·51	
0·60	0·592	Commencement of cast.
	0·592	End of cast.
0·65	0·668	
	0·660	
0·7	0·708	
	0·700	
0·8	0·804	
	0·804	

DISCUSSION ON MR. THIELEN'S PAPER.

Mr. **Percy Gilchrist** said that, in commencing the discussion upon that interesting paper, he wished to be allowed to congratulate Herr Thielen on the very clear way in which he had put the matter before them. He fully endorsed the necessity for the process. It was well known by all who had anything to do with the basic process, that it was remarkably easy to make very soft steel, but very difficult and required a great deal of skill to make steel with a regular percentage of carbon of over ·45 or ·50 at the outside. Consequently, when his friend Mr. Darby, at the outset, told him of his process, he immediately went down to see it, and had followed it step by step with the greatest interest. Any one conversant with the basic open-hearth and the basic Bessemer would remember that there were two discoveries required to perfect the process in the case of the basic open-hearth, and three discoveries in the case of the basic Bessemer process. The process of Mr. Darby for giving a regular amount of carbon from 0·15 up to 0·9 or 1 per cent. was one of these discoveries. Mr. Darby had carried on the process, as the author had told them, in the basic open-hearth, and his friend, Mr. Thielen, was so satisfied with what he saw there, that he thought he could apply it with success to the basic Bessemer system; and great thanks were due to him and his staff for the successful way in which they had overcome some of the difficulties which appeared at first in applying the process to basic Bessemer working.

In July of the present year his friend, Mr. Arthur Cooper, the general manager of the North-Eastern Steelworks, which they would remember was a basic Bessemer-producing plant, producing some 3000 tons of basic ingots per week, went over with himself to Ruhrort, where they were permitted to see everything that they desired to see, both as to the basic open-hearth and the basic Bessemer working. He would not weary them with the details of what they saw on that visit. They were much more clearly put in the paper they had just heard than he could put them before them. Briefly, he might say that everything that Mr. Thielen had stated in his paper they had seen for themselves when they made that visit. So satisfied was Mr. Cooper with the results that he saw obtained, that within a very few weeks of his return, speaking from memory, he carburised some hundreds of tons by that method at the North-Eastern Steel Company's works; and he (Mr. Gilchrist), knowing that the paper was coming on, asked him to be good enough to give him some results that might be taken as typical of all his results.

To begin with, he might say that, in one respect, their experience there differed from the German experience. They would notice that the German experience showed a slight, but only a slight, rephosphorisation. Mr. Cooper's experience, up to the time he left England at any rate, showed that they had no rephosphorisation at all. To that extent it was an improvement. In a letter dated September 16, Mr. Cooper said: "In accordance with my promise, I hand you on the fly-leaf the estimate of carbon in each of the nine ingots in Blow 370, and in each of the eight ingots in Blow 378, together with the phosphorus and the several manganese results. I also hand you the mechanical tests of rails made from the above blows, which you will see give exceedingly regular results." He would not trouble to read them. They would be handed in, but he would simply cite an example. In Blow 370 they aimed at a carbon between 0·45 and 0·50. They got 0·44 of carbon as a minimum, and 0·48 as a maximum, in the nine ingots. The phosphorus in each ingot appeared to be 0·046. The manganese varied from 0·58 to 0·69. The falling-weight test was applied to rails from this change. The rail was 30 feet long, 3 feet 6 inches bearing, 20 feet drop, and weight 16 cwt. There were four blows. The first blow gave 1⅝ inch deflection, the second 1½. The rail was then reversed and had two more blows, each of 20-feet drop, and it stood. In the next blow the carbon aimed at was 0·30 to 0·35. The carbon obtained was, the lowest 0·27, and the highest 0·35. The phosphorus varied from 0·06 in the first, second, and fourth ingots, to 0·07 in the other five ingots. The manganese was 0·46 to 0·58. In the test of 378 there was at first deflection of 1⅝ inches, and then, on the rail being reversed, it stood each time. There was only one point that Mr. Cooper told him he had found that they had to be careful about, and that was in the choice of the material that they used for decarburising. His experience, however, so far had been, that they must avoid material having much ash, choose something that had as little ash as possible, and especially little oxide of iron. If they did that, they would be able to obtain what he thought was the right material, namely, an alloy of iron, carbon with a minimum of manganese, and they would get a material that would roll like copper.*

Mr. G. J. Snelus, F.R.S., said it had given him great pleasure to listen to the paper of his friend Mr. Thielen. Many of their members would remember that so long ago as 1878, when he read his first paper upon the basic process, he pointed out that there was an opportunity then of making a steel which would exceed in quality the famous tool and cutlery steel made from Swedish material, inasmuch as they were now able to produce a metal which had less phosphorus than that celebrated product from Sweden. The first piece of steel which was made in 1872 by the basic process contained only 0·001 per cent. of phosphorus from a metal containing 1½ per cent. Such results were repeatedly obtained by his friends and co-workers, Mr. Thomas and Mr. Gilchrist, and it occurred to him very early that if it was possible to get a basic material so pure as that, it must undoubtedly in the future take the place of even Swedish metal. Mr. Darby had very kindly allowed him to see his process at the works at Brymbo last year, and in their journey over there, Mr. Darby

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* To substantiate the statement made in my remarks on this paper, I have obtained from Mr. Cooper, of the North-Eastern Steel Company, the following figures giving the phosphorus in the metal both before and after carburising:—

Blow No.	Soft Steel before Carburising. Phosphorus per Cent.	Hard Steel after Carburising. Phosphorus per Cent.
82,764	·06	·06
82,766	·07	·07
82,768	·06	·06
82,774	·07	·07
82,780	·07	·07
82,781	·07	·07
82,782	·07	·07
82,791	·07	·07
82,794	·07	·07
82,798	·07	·07

Therefore it is perfectly clear from the above figures that the steel can be carburised without rephosphorisation, but to attain this result it is necessary very carefully to keep back the whole of the slag.—P. C. G.

admitted that he was working upon the suggestion that he (Mr. Snelus) then threw out. But a point of still further importance was that he had discovered that solid carbon would recarburise that steel. It was quite evident that they could recarburise a pure metal with other compounds. Take cemented steel, for instance; that could be used for recarburising. But the step in advance of using the solid carbon was a very great one, and there was no doubt it would tend to revolutionise the manufacture of steel. He ventured, however, to say that he thought its most important application would be in the manufacture of fine steel, because he had found years ago, in investigating what was the difference between steel made from Cumberland iron, which contained say 0·03 per cent. of phosphorus, and that made from Swedish iron, which contained about one-half the quantity, that it was the phosphorus in that immeasurably small quantity that prevented their Cumberland iron from being used for cutlery steel, inasmuch as that quantity of phosphorus produced brittleness, and prevented their getting a keen-cutting edge. When he found that to be the fact, it naturally occurred to him that if they could produce a steel with as small a quantity of phosphorus as they knew, they could know that that would ultimately be the basis for fine steel. It did not occur to him that they should attempt to use that process of recarburising for the coarser grades of steel for rails and for plates; but, from the discovery of Mr. Darby, it seemed that they could also apply the process of recarburising to the coarser grades of steel, and it certainly reflected very great credit upon him, and upon their friend, Mr. Thielen, for the clever way in which they had carried the process to success.

Mr. THIELEN, in reply, said there were no points in the discussion which required to be cleared up. He was happy to hear that they generally agreed with his paper.

On the motion of the CHAIRMAN, the usual vote of thanks was accorded to Mr. Thielen.

INTERNATIONAL STANDARDS FOR THE ANALYSIS OF IRON AND STEEL.

NOTES ON THE WORK OF THE AMERICAN COMMITTEE.

BY JOHN W. LANGLEY, PITTSBURGH, PA.

In the summer of 1888, it was the fortune of the writer to present the subject of the desirability of establishing a set of samples of steel, which should be analysed with extreme care, in order that they might become standards to which scientific and commercial analyses of iron and steel could be subsequently referred; also, that greater uniformity in the results of analyses might be brought about, since these standards would bear towards analytical methods somewhat the position which the original units of weight and length, the gramme and metre, or the pound and yard, preserved in Paris, London, and Washington, do to the mechanical arts.

The plan met with hearty co-operation, with the result that committees were appointed in Sweden, Germany, France, England, and America to receive the material, and to see that the necessary analyses were executed.

In England, the British Association for the Advancement of Science appointed a committee, which subsequently published a plan of operations for that country, reports of which will be found in the British Association *Transactions* for 1888 and 1889.

The writer of this paper was entrusted with the duty of preparing the material, and distributing it to the five countries named. This has been done, and analytical work on the steel is now going forward.

In the United States a committee of seven chemists was appointed to make the analyses, consisting of Andrew A. Blair, Philadelphia, Pa.; Regis Chauvenet, Golden, Colo.; Thomas M. Drown, Boston, Mass.; Charles P. Dudley, Altoona, Pa.; John

W. Langley, Pittsburgh, Pa.; Albert B. Prescott, Ann Arbor, Mich.; Porter W. Shimer, Easton, Pa.

This committee held a meeting at Washington, February 19, 1890, and came to the decision that the whole subject of the existing methods for the determination of carbon in iron and steel seemed to be affected by so many discrepancies and differences of opinion, that, before beginning work on the international standards, it would be desirable to make a preliminary study of methods. Accordingly, the writer was asked to prepare some additional material which could be used in somewhat large quantities for the above purpose only, and which should be known as the "experimental standards," to distinguish them from the "international ones."

EXPERIMENTAL STANDARDS.

Mode of Preparation.—An ingot of tool-steel, 3½ inches square, poured from a single crucible in which the metal had been thoroughly "dead-melted," was heated and hammered barely enough to round off the corners. The ingot was then cut into two pieces, one of which was reheated and hammered down to a bar 1½ × 3¾ inches. The other half of the ingot was turned in a lathe with a blunt tool, exactly as in the manufacture of the international standards, and the turnings, after sifting from fine dust, were thoroughly mixed and then sealed up in glass jars. The hammered bar was drilled, and the drillings were similarly treated. This material was given by the Crescent Steel Company of Pittsburgh.

The object in view was to have two bodies of metal presumably identical in original composition, but one of which had received a large amount of mechanical work, the other approximately none. These samples are respectively designated "Experimental Standard Ingot" and "Experimental Standard Hammered."

Scope of the Proposed Work.—The committee decided to limit the investigation to the following points at first:—

a. The best method of conducting the igneous combustion of the carbon previously liberated from the metal by a solvent.

b. The best method of conducting the aqueous combustion of the carbonaceous residuum left by the solvent.

c. The influence of the solvent on the quantity and mode of release of the carbon.

For division *a*, it was decided to commence with a study of the method of burning the carbon in a stream of oxygen.

This work was assigned to Messrs. Blair, Dudley, and Shimer.

For *b*, the examination of oxidation methods by hot solutions of sulphuric and chromic acids. Work by Mr. Langley.

For *c*, the use of a double chloride of copper and ammonium, or of copper and potassium, either neutral or acid. Work by Messrs. Blair and Dudley.

A description of the apparatus for igneous combustion is as follows:—

The apparatus used by Dudley consisted of an ordinary Bunsen furnace with fifteen burners, in which was a porcelain combustion-tube, ⅝ths of an inch internal diameter, and 18 inches long. Inside this tube, about 3 inches from the end, toward the absorption apparatus, was granulated and porous oxide of copper, occupying about 4 inches of the length of the tube, and filling the bore. This was held in place by asbestos plugs at either end. Next to the oxide of copper, towards the boat, was placed a roll of metallic silver about 4 inches long, nearly filling the bore of the tube. Rubber corks were used at each end. The combustions were all made in oxygen gas, using air to finish the aspiration and clean out the tube. The oxygen gas used was obtained in the market in cylinders, the gas being compressed to 250 pounds per square inch. Between the oxygen-holder and the combustion-tube was placed, first, a copper tube about 4 feet long and one quarter-inch in diameter, fitted with three coils at the middle; next, a potash-bulb, and, after that, a chloride of calcium tube. All the oxygen gas and the air used in the combustions was passed through these parts. The copper coils were kept red-hot by a Bunsen burner during the passage of the gases, the idea being to burn any possible traces of combustible in the gas or air, and absorb the CO_2 formed before they should go into the combustion-tube. Between the absorption end of the combustion-tube and the potash-bulbs were, first, a washing-tube containing about five cc. of sulphate of silver solution, with perhaps one-half gramme of silver sulphate; and next, a chloride of calcium tube. The potash-bulbs were of the Geissler form, of small size, made to order. These were fitted with a small chloride of calcium tube containing chloride of calcium simply, and commonly called the "prolong." The whole absorption-apparatus weighed, when charged, about sixty grammes. The absorbing solution in the bulbs was the ordinary caustic potash solution recommended by Fresenius. The absorption apparatus was protected against the aspirator bottle by a full-size chloride of calcium tube. The joints were made with ordinary rubber tubing. The carbon from the steel was caught on an abestos filter in a platinum boat, and dried after very complete washing at about 90° C. The boat, with its filter and carbon, was put into the tubes without transfer. During combustions, a slight pressure above the atmosphere was always maintained in the combustion-tube. Careful experiments show that the sulphate of silver washing-tube is a complete protection against hydrochloric acid, and the metallic silver in the tube was relied on for protection against free chlorine or other chlorine compounds. The time of making a combustion was about an hour and a quarter; fifteen to twenty minutes being taken to heat the oxide of copper, about half-an-hour for the burning, and twenty-five to thirty minutes for the air aspiration. Blair's apparatus is substantially the same as the above. His purifying train following the combustion-tube contains a tube of anhydrous sulphate of copper on pumice-stone. The tube is always freshly filled.

Shimer's apparatus is a porcelain tube containing oxide of copper. A stream of purified oxygen is used. An anhydrous copper sulphate absorbing-tube is employed, and then the customary $CaCl_2$, KHO, and $CaCl_2$ absorbents.

Preliminary Results by Oxygen Combustion.—In the following analyses a solution of double chloride of copper and ammonium, except where otherwise noted, was used as the solvent of the steel. The carbon sponge was washed with dilute HCl and water until the filtrate was free from chlorine; then the asbestos, with adhering carbon, was put into the combustion-tube. These determinations were made before the elements of uncertainty attaching to the use of double chloride were discovered, and it will be seen in the latter part of this paper that quite different numbers can be obtained.

Under date of April 22, 1890, Dudley reports: "Experimental standard ingot" contains:—

	Per Cent.
Carbon	1·058
„	1·065
„	1·052
„	1·058
Average	1·058

Ditto, "hammered standard:"—

	Per Cent.
Carbon	1·050
„	1·051
„	1·051
„	1·060
„	1·050
„	1·056
„	1·056
Average	1·053

Under date of April 5, 1890, Blair reports that, using double chloride of copper and ammonium, with enough ammonia added to produce a slight cloud, and re-dissolving the basic salts formed in acidulated double chloride, he obtains:—

	Ingot. Per Cent.	Hammered. Per Cent.
Carbon	1·016	1·022
„	1·013	1·020
„	1·015	1·025
„	1·010	1·022

He then weighed out four portions of the "ingot" sample, and added to each 200 cc. double chloride of copper and ammonium, after adding to each the following amounts of strong HCl:—

	Carbon. Per Cent.
10 cc.	1·048
20 „	1·048
30 „	1·048
40 „	1·051

He then took four portions of the "hammered" sample, and treated them each with 200 cc. of double chloride and 20 cc. HCl. Results:—

	Per Cent.
Carbon	1·046
„	1·046
„	1·044
„	1·049

Showing that the addition of HCl in excess of 5 per cent. does not sensibly vary the results.

A combustion of sugar at the same time showed:—

	Per Cent.
Carbon	42·05
„	42·14
Theory	42·11

In answer to the suggestion that possibly oxides of nitrogen might be derived from the breaking up of ammonia retained by the carbon sponge, Blair reports, under date of April 17th, that he has made four combustions on the "ingot" sample, using a four times re-crystallised double chloride of copper and potassium.

	Per Cent.
No. 1, Carbon,	1·010
No. 2, „	1·044
No. 3, „	1·012
No. 4, „	1·022

No. 1 was dissolved in the filtered solution of the above double chloride.

No. 2 was dissolved in 200 cc. double chloride, with 200 cc. strong HCl.

Nos. 3 and 4 were dissolved in the filtered double chloride, to which enough potassic hydrate had been added to produce a slight permanent precipitate.

Blair offers the hypothesis that a strictly neutral or slightly alkaline double chloride dissolves a small portion of the carbonaceous matter, which is consequently lost so far as the combustion is concerned. Therefore, the addition of acid, by preventing this action of the liquid on the carbon sponge, will give higher and more nearly accurate results.

That the use of an acid double chloride solution gives higher results was promptly verified by Dudley and Langley. This subject is more fully discussed in the latter portion of this paper.

Shimer reports, April 25th, that by using 4 grammes of steel in a neutral solution of double chloride of copper and ammonium, he obtains:—

"Ingot," average of two combustions, 1·055 per cent.

"Hammered," average of two combustions, 1·052 per cent.

Preliminary Results by the Wet Method.—The chromic acid combustion was conducted in an apparatus originally designed by Professor Hermann Wedding, although the method of absorption used by him has been radically modified. Wedding's design consists of a flask capable of holding 220 cc., and provided with a glass cap of two tubulures. Through one of these passes a funnel-tube with stop-cock, and through the other the delivery-tube, surrounded by a water-jacket. All the joints are of ground-glass.

The merit of this apparatus is its compactness and its freedom from rubber or cork joints, at least in the parts liable to come in contact with chromic acid. The absorption-train, which is wholly different from Wedding's, consists of:—

1st, A tube filled with pumice-stone and anhydrous sulphate of copper.

2nd, A small washing-bottle containing the "pyro" solution referred to later on.

3rd, A solution of sulphate of silver.

4th, A wash-bottle of strong sulphuric acid.

5th, A chloride of calcium tube, having a small plug of moist cotton in its anterior end.

6th, A Liebig tube, containing potassic hydrate solution.

7th, A U tube, having solid potassic hydrate in its anterior limb, and granulated calcium chloride in the posterior one.

8th, A chloride of calcium guard-tube.

9th, An aspirator filled with water.

The absorption portion for CO_2 is constituted by Nos. 6 and 7. The other parts, except Nos. 2 and 3, need no explanation, since they are well-known adjuncts of the chromic acid method described in such treatises on analysis as those of Fresenius and of Blair.

The method of conducting a combustion is to place the carbon, which has been liberated from 3 grammes of steel by the action of 150 cc. of solution of double chloride of copper and ammonium, to which 10 cc. of HCl has been added, into the flask, and run in through the funnel-tube 100 cc. of a solution made by dissolving 10·5 grammes CrO_3, 66 cc. H_2O in 210 cc. strong H_2SO_4. Purified air is drawn through at the end of the combustion.

The train at first used did not contain the "pyro" tube No. 2.

Under these conditions the following numbers were obtained from the "experimental ingot" standard:—

	Per Cent.
Carbon	1·099
,,	1·145
,,	1·040
,,	1·058
,,	1·109

A search was instituted to find the cause of these discordant results. It is well known that the carbon sponge from the action of the double chloride retains chlorine or hydrochloric acid in a form not removable by washing. Suspicion at once fell upon the HCl known to be evolved from the carbon sponge.

A series of blank combustions was made, and also mixtures of air and HCl were drawn through the absorption-train. It was found that the anhydrous $CuSO_4$ would only stop HCl when it was perfectly fresh and in relatively large quantity, a quite small degree of hydration impairing its absorbing powers seriously. A tube containing an aqueous solution of sulphate of silver was then added to the $CuSO_4$ tube, with the result that vapours of HCl are perfectly and completely arrested. When this point was established, black combustions were made and small quantities of chlorides introduced into the chromic acid mixture; it was invariably found that the potash-bulbs gained in weight. As one example out of many, the following is quoted:—

One-tenth gramme of NaCl in generating flask; $CuSO_4$ and Ag_2SO_4 absorbents were interposed. The silver solution showed not a trace of chloride, and yet the potash-train gained ·0055 gramme.

This gain appears to be owing to chloro-chromic anhydride, or to oxides of chlorine, not absorbable by copper or silver sulphates.

This observation is not new, for it had previously been noted by A. A. Blair that chloro-chromic anhydride was not arrested by copper sulphate.

After a long series of experiments an absorbent for these bodies has been found in the following solution:—

Pyrogallic acid	0·2 gramme.
Potassic oxalate	5·0 ,,
Sodic chloride	3·0 ,,
Sulphuric acid	0·2 ,,
Water to make up to	20·0 cc.

The theory of the action of this mixture is as follows:—

The pyrogallic and oxalic acids are deoxidants. The sulphuric acid will form potassic sulphate, liberating a very little free oxalic acid to guard against the solution becoming alkaline. The sodium chloride is not essential, but it is advantageous by diminishing the solubility of CO_2 in the liquid.

The action of this absorbent is very energetic. It will allow HCl to pass through it without change, but the smallest traces of free chlorine, or of oxides of chlorine, or of chloro-chromic anhydride, at once turn the solution brown, and are either arrested or changed into HCl. Indeed, as a qualitative reagent this liquid will approximate to iodised starch-paper.

In using this in the absorbing train, the copper sulphate tube may be dispensed with, the pyrogallic liquid being used in its place, and followed by a sulphate of silver tube, so that the train between the generating flask and the potash-bulbs will contain— 1. A cooling tube; 2. The "pyro;" 3. The sulphate of silver; 4. Sulphuric acid; 5. Chloride of calcium.

Blank "combustions" were made as before with NaCl, using the pyro-train till it was proved that there was no systematic gain in weight of the potash-bulbs.

As examples of carbon oxidation in *presence of chlorides:* Taken ·0712 gramme sugar with a crystal of NaCl; found ·1098 gramme CO_2. Theory ·110 gramme. Taken ·030 gramme Ceylon graphite, of about 3 per cent. ash; found ·0292 carbon, equal to 97·3 per cent. carbon.

The following analyses were made, using the new train:—

	Per Cent. Carbon.
Experimental standard, hammered	1·075
,, ,, ,,	1·070
,, ,, ingot	1·041
,, ,, ,,	1·034

It seemed possible that the carbon sponge left on the asbestos, after filtering from the double chloride solution, might suffer a slight oxidation and loss of carbon while drying. A set of duplicate analyses were therefore made on a variety of steels. The terms "wet" and "dry" below refer to the state of the carbon sponge when introduced into the chromic acid flask. The drying was performed at a temperature not above 100° C,

	Per Cent. Carbon.	
	Wet.	Dry.
Steel A	·981	·936
„ B	·836	·813
„ C	·904	·891
„ D	1·054	1·073
„ E	1·145	1·154
„ F	1·095	1·108
„ G	1·027	·968
Pig	3·695	3·722
Totals	10·737	10·665
Average	1·342	1·333

These determinations were made before the discovery of the variability of action of double chloride with age and manner of crystallising, to be pointed out hereafter. Moreover, they were distributed over a period of three months, so that some of the differences may be properly attributed to the chlorides used. Still, these would pretty well neutralise each other in sixteen determinations, so that the practical identity of the final averages would appear to show that the sponges do not lose appreciable amounts of carbon by drying.

On the other hand, the "Hammered" Standard, similarly treated, but having the sponge dried in an air-bath at a temperature not exceeding 120° C., gave—

	Wet. Per Cent.	Dry. Per Cent.
Carbon	1·064	1·027
„	1·059	1·023
„	1·064	1·018
„	1·045	1·032
Average	1·058	1·025

Apparently, therefore, there is a loss of carbon by drying the sponge at temperatures above 100° C. The same double chloride, acidulated, was used in these eight determinations.

Mode of Release of Carbon.—In pursuance of the special work assigned to Dudley, in a study of the phenomena attending the release of the carbon from its connection with iron in the steel, some quite surprising results have been obtained. It is, perhaps, not too much to say that sufficient work has already been done to throw doubt on the accuracy of all recent carbon determinations made with preliminary solution of the steel in double chloride of copper and ammonium.

Dudley began his study of this problem of the release of the carbon by quite an amount of preliminary study on the reliability of his apparatus and method of making combustions. A number of modifications were tried, but finally the apparatus and method previously described were settled upon, and this apparatus and method were checked up by the following determinations :—

In an ordinary glass combustion-tube, some 60 grammes of the well-known combustion mixture of chromate of lead and bichromate of potass were placed, taking care that the material did not reach to either end of the tube, and holding it in place at each end by asbestos plugs previously ignited. The tube was then placed in the furnace and a combustion made in the regular way, the position of the material, not reaching to either end, allowing the whole of it to be uniformly heated. This combustion was simply a blank to eliminate any possible error due to impurities in the combustion mixture. A small increase in weight in the absorption apparatus was found, and a second blank gave exactly the same results. This being done, three samples of 3 grammes each of the experimental standard ingot were treated with 200 cc. each of the same double chloride solution rendered acid by 10 cc. HCl. As this solution of double chloride will be referred to hereafter, we will say that it was made in Dudley's laboratory by obtaining from the market commercial chloride of copper and commercial chloride of ammonium, dissolving these in water, and mixing them in the proportions to form a double chloride containing one molecule each of the two salts. A small amount of free ammonia was added, enough to cause a perceptible separation of hydrated oxide of copper. The solution was then allowed to settle, and always filtered through previously ignited asbestos before using. This will be called solution "A," and it will be observed that the solution had not been crystallised. After solution was complete, the three tests were filtered into platinum boats and three combustions made. Two of these combustions were made in glass tubes, using exactly the same amount of combustion mixture as in the case of the blanks above described, and following the same manipulation, except that the boats with their carbon were buried in the combustion mixture in the tube. The third combustion was made in the apparatus, and by the method previously described as Dudley's apparatus and method. The results obtained from these three combustions were as follows:—

	Per Cent.
Combustion mixture No. 1, after allowing for blank, gave carbon	1·102
Combustion mixture No. 2, after allowing for blank, gave carbon	1·109
Combustion with Dudley's apparatus and method	1·106
Average	1·106

The results were regarded as showing that Dudley's apparatus and method gave fairly reliable results so far as the combustion was concerned.

But these results were confirmed by two further tests, as follows:—First, A direct combustion of crystallised and pulverised sugar in the same apparatus, and immediately following the last steel analysis above, gave—

	Per Cent.
Carbon	42·02
Theoretical carbon in sugar	42·11

This was followed, secondly, by a blank combustion, everything being done exactly as in a regular combustion, except that nothing was put in the combustion-tube. This blank showed a loss in the weight of the absorption apparatus of two-tenths of a milligramme.

The apparatus and method being regarded as satisfactory, attention was next given to the release of the carbon. Experiments were planned to demonstrate the effect of different states of dilution of the double chloride solution on the release of the carbon; also, to determine whether large or small amounts of double chloride solution changed results, and also to determine whether varying amounts of chloride of ammonium relative to the chloride of copper present produced any change. Before this part of the work was fairly entered on, however, a shipment of crystallised double chloride was obtained from the market. Since it had already been noticed in the work done on apparatus and method previously alluded to that discordant results were frequently obtained, it was at first suspected that the apparatus and method were at fault, but after the tests of the apparatus, above given, were made, suspicion fell on the double chloride, and accordingly a nearly saturated solution was made from the shipment above alluded to. This solution will be called solution "B." Four combustions of the experimental standard ingot were made, using 200 cc. of solution "B" rendered acid with 10 cc. of HCl. These gave results as follows:—

	Per Cent.
No. 1, Carbon,	1·070
No. 2, ,,	1·067
No. 3, ,,	1·060
No. 4, ,,	1·065
Average	1·065

These results, it will be observed, are a trifle over ·04 per cent. lower than were obtained with the same steel, with the same apparatus and method, but using the uncrystallised double chloride solution "A." The problem at once arose how to reconcile these discrepancies. Obviously, if the apparatus and method could be trusted, either the solution "A" contributed something to the absorption apparatus, which was weighed and counted as carbon, or solution "B" dissolved and carried off some of the carbon in the steel—or possibly both. Who could tell where the truth lay?

The first attempt to unravel the mystery consisted in taking 450 cc. of solution "A" with 25 cc. of HCl, and adding to it 1 gramme of steel. After the reaction was complete, and the solution had been thoroughly mixed, it was filtered through asbestos. The result of this treatment was that this 450 cc. of solution "A" had now in it some sub-chloride of copper, some chloride of iron, and also carbon liberated from steel which had been floating around in it, affording an opportunity for any material that might be separated from the solutions by the reaction to attach itself and be filtered out. The reasoning was as follows:—If double chloride solution "A" contains any carbonaceous material in solution which separates when the solution is treated with steel, thus causing high results, a part, at least, of this material will separate when the 450 cc. are treated with 1 gramme of steel, and be removed by the subsequent filtration, and consequently combustions made with the use of this treated double chloride solution "A" will show lower results. Two combustions were accordingly made of the experimental standard ingot, everything being exactly as in the previous combustions, except the use of the treated double chloride solution "A." These combustions gave:—

	Per Cent.
No. 1, Carbon	1·076
No. 2, „	1·070
Average	1·073

Here was a reduction of a little over .03 per cent. from the figures obtained using solution "A" untreated with steel, and the figures seem to indicate quite clearly that uncrystallised double chloride solution "A" contained something in solution that separated during the reaction with the steel, and gave erroneous and too high results.

In confirmation of this view, the following experiments were made:—200 cc., the usual amount for a combustion of solution "A" with 10 cc. of acid, were treated with 5 grammes of the experimental standard ingot, instead of 3; the assumption being, if there is a certain amount of carbonaceous matter in solution "A" which comes out during the reaction with the steel, lower results will be obtained if this error is divided over a larger amount of steel. Two combustions were made on this plan, which gave results as follows:—

	Per Cent.
No. 1, Carbon	1·049
No. 2, „	1·082
Average	1·065

It is possible that the first of these duplicates is a little low, as this carbon sponge from the larger amount of steel was a little difficult to manage in the boat; but as both the results are lower than those previously obtained from solution "A," it is evident they point in the direction that there is something in solution "A" that should not be there.

One more experiment was made on solution "A," as follows: 1000 cc. of this solution was treated with 50 cc. of HCl, and allowed to stand for some time. This solution was then filtered on the boat, and although nothing was visible to the eye, a combustion was made. The absorption apparatus showed an increase in weight of 3½ milligrammes. This corresponds to a trifle over ·006 per cent. of carbon in the steel which had been used in all the previous tests. This apparently indicates that although solution "A" probably contains something which it should not, that something only separates very slightly when the solution is treated with acid.

Thus far the evidence seems to point quite strongly in the direction that uncrystallised double chloride solution contains some carbonaceous matter which separates during the reaction with the steel. But who knows that crystallised double chloride does not also contain carbonaceous matter? And still further, who knows that either crystallised or uncrystallised double chloride does or does not dissolve some of the carbon of the steel during the reaction, and thus produce a loss?

Upon the first of these questions the following experiments were made:—450 cc. of solution "B," which, it will be remembered, was made from crystallised double chloride obtained from the market, were treated with 1 gramme of steel and acid, as previously described for solution "A," and two combustions made. These two combustions gave:—

	Per Cent.
No. 1, Carbon	1·060
No. 2, ,,	1·061
Average	1·060

These results are, it will be observed, only about ·005 per cent. lower than were obtained with the same solution untreated with steel, and seem to indicate that crystallisation removes at least the largest part of the carbonaceous material, such as was characteristic of solution "A." But the mother liquor, from which the crystals forming solution "B" were obtained, may not have contained any large amounts of carbonaceous matter, and so the evidence seems most conclusive.

In continuation of this same study, four more combustions were made, two of them using solution "B," but no acid, and the other two likewise using solution "B" and no acid, but treating the solutions with steel, as previously described. These combustions showed as follows:—

	Untreated. Per Cent.	Treated. Per Cent.
No. 1, Carbon	1·036	1·030
No. 2, ,,	1·035	1·024
Average	1·035	1·027

These results are about ·008 per cent. lower for the treated double chloride than for the untreated, but the number of analyses and the number of samples of crystallised double chloride experimented upon seem hardly sufficient to set at rest the question as to whether crystallisation completely removes the probable difficulty due to carbonaceous matter in the mother liquor.

Thinking that possibly carbonaceous matter might be introduced into the double chloride solution "A" by the commercial chloride of ammonium used in making it, four combustions were made, using some of the same shipment of chloride of copper alone which had been used in making solution "A." All four of the solutions had acid present. Two of them were previously treated with one gramme of steel, and filtered as already described; the other two were not so treated. The same steel was used as in all the previous cases; the combustions gave the following results:—

	Untreated. Per Cent.	Treated. Per Cent.
No. 1, Carbon	1·072	1·040
No. 2, ,,	1·056	1·050
Average	1·064	1·045

These figures, as will be observed, seem to indicate that part of the difficulty, at least, is due to the chloride of ammonium, since the chloride of copper alone gives nearly ·04 per cent. lower results than solution "A." They also seem to indicate that previous treatment with steel throws out something even from the chloride of copper alone. Too much importance should not, however, be attached to these results, as the reaction between the chloride of copper and the steel was very slow; and as acid was present, and it was impossible to keep the solution agitated continuously, it is probable a slight loss of carbon may have occurred. The variation in the duplicates may possibly be accounted for in this way.

Up to this point, the evidence obtained seems to indicate:

1st, that uncrystallised double chloride made from commercial materials probably contains carbonaceous matter in solution; 2nd, that this may come partly from the chloride of copper, and partly from the chloride of ammonium; and 3rd, that crystallisation is probably advantageous in diminishing, if not completely removing, this difficulty. But some points are not quite certain, and accordingly the following experiments were undertaken to throw as much light as possible on the subject.

Commercial chloride of copper and commercial chloride of ammonium were obtained from the market. These were dissolved in hot water and mixed in the proportions to give a salt containing one molecule each of the two chlorides. On cooling the hot solution to a low temperature, a large crop of crystals of the double salt was obtained. The mother liquor was drained off from these crystals and set aside. Also, a portion of the crystals obtained were rinsed with pure water and set aside. The remainder of the crop of crystals was again dissolved in hot water, evaporated a little, and cooled, giving a second crop of crystals, from which the second mother liquor was drained off; they were then rinsed with pure water. The first and second crop of crystals were then each dissolved in water, forming nearly saturated solutions at ordinary temperatures. This gave three solutions to work with, viz.: (1) The mother liquor from the first crop of crystals; (2) a solution of the first crop of crystals; and (3) a solution of the second crop of crystals. In other words, solutions of uncrystallised, once crystallised, and twice crystallised double chloride. The mother liquor solution was treated with ammonia sufficient to give a slight precipitation, and then filtered through asbestos. It was then divided into two parts, and one part treated with HCl to the amount of 5 per cent. The part treated with ammonia alone we will call "basic mother liquor," and the other "acid mother liquor." Three combustions each were made with these two solutions, using the same steel and everything else as previously described. The results obtained were as follows:—

	Basic Mother Liquor. Per Cent.	Acid Mother Liquor. Per Cent.
No. 1, Carbon	1·086	1·145
No. 2, „	1·081	1·130
No. 3, „	1·067	1·150
Averages	1·078	1·142

Two results are quite noticeable in these figures: 1st, The acid mother liquor gives higher results than any previous determination; and 2nd, The differences between the basic and acid solutions is greater than in any previous case.

The second solution, viz., that from the first crop of crystals, was divided into two unequal parts. The smaller of these was treated with ammonia, and filtered as previously described, forming what we will call "basic first crystals." The other part was filtered through asbestos, and divided into two parts, one of which was treated with acid, as above described, and will be called "acid first crystals." The other part was left without further treatment, and will be called "neutral first crystals."

Three combustions each were made with these three solutions, showing as follows:—

	Basic First Crystals. Per Cent.	Neutral First Crystals. Per Cent.	Acid First Crystals. Per Cent.
No. 1, Carbon . .	1·026	1·029	1·070
No. 2, „ . .	1·017	1·034	1·081
No. 3, „ . .	1·031	1·029	1·082
Average, . .	1·027	1·031	1·077

The marked diminution in the amount of carbon between the mothor liquor and the first crop of crystals is very noticeable. In the basic results the difference is ·051 per cent., and in the acid results the difference is ·065 per cent. It will also be observed that there is a slight difference between the results with the basic and the neutral crystals.

With the second crop of crystals only basic and acid combustions were made, the solutions being obtained as previously described. The results obtained were as follows:—

	Basic Second Crystals. Per Cent.	Acid Second Crystals. Per Cent.
No. 1, Carbon	1·016	1·049
No. 2, „	1·028	1·056
No. 3, „	1·023	1·052
Average, ...	1·023	1·052

These results, taken in conjunction with what precedes, are, to our minds, exceedingly interesting. The marked diminution in the amount of carbon obtained with the second crystals over the mother liquor, especially in the acid solutions, cannot fail to be noticed, and this would seem to indicate that double chloride made from commercial materials without crystallisation contains carbonaceous matter. This point would seem to be settled if it were not for the doubt whether the double chloride does not dissolve some of the separated carbon. Upon this point no positive data have yet been obtained. Two points further seem worthy of note. 1st, The basic first and second crop of crystals give practically the same results, while the acids do not; and 2nd, The farther away from the mother liquor, the nearer the results from the basic and acid treatment come together. To our minds these facts, together with what precedes, seem to indicate that possibly the commercial material contains dissolved cellulose, and that crystallisation diminishes its amount. Thus with the material used in the above experiments, once crystallising diminished the amount of cellulose, so that the basic liquid retained in solution what was left (since alkaline oxide of copper is a well-known solvent of cellulose), while the acid solution, even of the twice crystallised salt, still gives up a little cellulose to the carbon sponge.

In the special ground covered by Dudley in a study of the release of the carbon, the results of which are given above quite at length, the services of Dudley's principal assistant, Mr. F. N. Pease, have been found of the greatest value. He made all the combustions, and his suggestions have been most pertinent and useful.

A few attempts have been made to estimate the carbon in the experimental standards by methods not employing double chlorides, but not with much success.

Langley had proposed dissolving the steel in a hot solution of copper sulphate made as nearly neutral as possible, then filtering and burning the mixed copper and carbon sponge in oxygen.—*American Association for Advancement of Science*, vol. xxiv. 1875.

This method occasionally gives too low results, because of the impossibility of being sure that the last particles of steel are dissolved. Dudley made the following trials on the ingot standard :—

$CuSO_4$ was ignited to remove possible organic matter, then dissolved and filtered. The solution was made as neutral as possible, and allowed to stand on the steel several days. Result :—

	Per Cent.
Carbon	1·011
„	·972

Then to 300 cc. of the sulphate solution was added 15 cc. HCl. The attack of the steel was rapid, but some gas was evolved. Result:—

	Per Cent.
Carbon	1·002
,,	1·036
,,	1·040

He then tried attacking the steel by solid silver chloride under water, and burning the silver and carbon sponge. Result on "hammered" standard:—

	Per Cent.
Carbon	·796

Langley made two determinations by putting the steel directly into the chromic-sulphuric acid mixture, without previous treatment by chlorides. Result on "hammered" standard:—

	Per Cent.
Carbon	·788
,,	·790

In this case more gas was evolved than what corresponded to the CO_2. It was found that methane would pass through the boiling chromic mixture without sensible oxidation; therefore, some of the carbon of the steel may have escaped in union with hydrogen.

SUMMARY.

The conclusions here presented are not those of the committee in their official capacity. They are the views provisionally held by the members whose work is given above.

First, The combustion of carbon in a porcelain tube in a stream of purified oxygen, when the precautions indicated are used, gives sensibly accurate results.

Second, If the carbon contains chlorine, it is desirable to use a coil of metallic silver in the combustion tube, and it is apparently also *essential* to use some solution of silver, preferably the sulphate, in the purifying train.

Third, The chromic acid method is capable of burning all the carbon used. If this carbon also contains chlorine, then it is *essential* to use some deoxidant in the purifying train, preferably pyrogallic acid with oxalate of potash; also a liquid silver absorbent must follow the deoxidising tube. Under these conditions this method gives sensibly accurate results.

Fourth, The use of a small quantity of HCl in a solution of the double chloride of copper and ammonium, invariably gives higher results than when a neutral solution is employed.

Fifth, There is doubtful evidence that the substitution of KCl for NH_4Cl in the double chloride is of any advantage.

Sixth, The most important discovery made by the committee in this work pertains to the variable action of the double chloride solutions. This apparently throws doubt on the reliability of all carbon determinations previously made by this reagent, since they show variations on the same steel lying between 1·016 and 1·150.

When the degree of acidity is kept constant, the apparent quantity of carbon found is affected by the mode of preparation of the double chloride, by its age, and by the number of times it has been crystallised.

Seventh, A carbon sponge derived from a double chloride solution does not appear to lose any carbon by drying at a temperature under 100° C., but loses if the heat is higher.

The problems now before the committee, as suggested by the above results, are:—The determination of carbon in steel by some direct process not involving the use of double chloride. The direct combustion of finely-divided metal in oxygen or chromic acid is one of these, or fusion in a mixture of bisulphate and bichromate of potash another.

The determination, if possible, whether a neutral or alkaline double chloride liquid may not dissolve a portion of the carbonaceous residuum, and thus lead to results which are too low.

The determination whether the addition of acid simply prevents this tendency, or whether the use of acid may not favour the separation of pre-existing organic matter in the liquid, and its retention by the carbon sponge, thus leading to results which are too high.

The investigation of the cause of the influence of repeated crystallisations of the double chloride on the apparent quantity of carbon.

Finally, it is to be presumed that many, if not all of the above points, have attracted the attention of other analysts, and the committee will be glad to learn of the results and experience of others along these lines.

DISCUSSION ON PROFESSOR LANGLEY'S PAPER.

Mr. **Snelus**, F.R.S., in opening the discussion, said he had been honoured by the British Association by being asked to take part in the investigation of the standards of steel, and they were indebted very much indeed to Mr. Langley for making the suggestion which led to the appointment of the British Association Commission; for if there was anything more tantalising to a chemist than another, it was to be told by outsiders who did not understand the speciality, "Oh, we have put two or three people together, and we have tested you all upon the same sample, and we find that you all disagree." He thought if they could arrive by some process at a standard system for analysis, it would not only be a great advantage to the ironmaster, but would be a great comfort to the chemist. With regard to the methods which had been mentioned in the paper, it seemed that the American members of the Committee had devoted their attention to a mode of estimating carbon which he had always, in his own practice, felt to be somewhat doubtful. He might be very old-fashioned, but when he was systematically engaged in estimating carbon, he never ventured upon estimating carbon by any but the direct method of burning the steel and burning the carbon with it. He knew that the method of estimating the carbon by the double chloride method was a very easy one, and much quicker than the method of the direct combustion of the steel; but in his own practice he had felt that there were a great many risks about it, and it had been pointed out to them that morning that those risks had been fully verified.

He hoped that the American members of the Committee would not discard the old direct combustion method because it was somewhat tedious. He thought himself that if the steel was sufficiently finely divided and the heat was intense enough, there was no difficulty whatever in burning all the carbon out of the steel by the direct method. And if that could be done, it was perfectly clear that the collection of the products and the weighing of them formed no difficulty whatever. If they adopted the process of dissolving out the carbon by any such method as the double chloride, they naturally must lose something from various causes. He thought that even the oxidation of the atmosphere had some effect; they could not properly perform the operation and exclude the atmosphere. Then, again, they knew that the common method of estimating the carbon by the coloration-test showed them that the carbon which was deposited from steel was very easily dissolved under the conditions in which they worked; and in any process where the carbon was dissolved there was great liability to loss. He therefore could not help thinking that the direct combustion method would be found in the end to be more accurate.

Professor LUNGE congratulated Mr. Langley most sincerely upon the initiative he had taken in producing uniform standards of analyses for iron and steel. He had himself had the honour of being connected with similar attempts, and, he was glad to say, successful attempts, in the great industries of sulphuric acid and of alkali making. Very similar, and perhaps even more serious, discrepancies existed here in the results obtained by different chemists, and by the co-operation of several workers, which he had the honour of bringing to a focus, they had produced a work which was a common basis of standard between the buyers and sellers of those important materials. What Professor Langley had initiated, and what was carried out in a number of the most important iron-producing countries, was exactly what they had done, on a smaller scale, in the German alkali trade; and he wished Professor Langley and his collaborators most sincerely a God-speed in that work. He would add another word, which illustrated the great benefits to be derived from this communion of ideas. He found in the paper a short paragraph which at once cleared up a difficulty that he had found to exist for a great many years past, and which had puzzled him considerably. In speaking of the methods of absorbing carbonic acid, and removing the impurities connected therewith, Professor Langley said that "it was found that the anhydrous $CuSO_4$ would only stop HCl when it was perfectly fresh and in relatively large quantity, quite a small degree of hydration impairing its absorbing powers seriously," Now that was the method of Fresenius, who proposed the use of the anhydrous cupric sulphate to remove the vapours of hydrochloric acid. For a great many years past he (the speaker) had found that the results of the ordinary carbonic acid estimates, not at all connected with the analysis of iron, gave those extremely unsatisfactory results; and, therefore, he had long ago given up the use of anhydrous cupric sulphate, and had worked in other ways, which he would not detain them to describe. He had never had time to investigate the question himself, but in this paper he found the explanation of the mishaps which he had frequently met with in his own work. He therefore had a personal reason for thanking Professor Langley for his labours. It was only a small item, but many others might be mentioned of the same kind. He thought that not only metallurgists, but chemists in general, had every reason to be most sincerely thankful to the International Committee, and to Professor Langley in particular.

Mr. J. E. **Stead** said it was with very great pleasure that he read Professor Langley's paper, and he was sure all English chemists were very much obliged to him, and to the Committee, for the very careful way in which they had gone into the matter. He himself had used the method of Mr. Blair for a great many years, and was under the impression that they could rely on their results. After reading that paper they were rather in a fog. His own solution of the double copper and ammonium chlorides had been slightly acid or not quite neutral; but he had not added the 5 per cent. of acid. He should be anxious to learn whether that 5 per cent. of hydrochloric acid would give in his laboratory the difference alluded to. He could say that many of the most prominent chemists in England, and those who had the most practice, had agreed very closely in their carbon combustion tests, and that if he was wrong, they must all be wrong. With reference to the remarks of Mr. Snelus, he thought that all chemists who were in the habit of making a large number of combustions would know very well that to burn up a sample perhaps a quarter or an eighth of an inch square in diameter, would probably take a week or a fortnight to complete. Now, unfortunately, the people who sent samples did not send them the material in that fine degree of powder which was necessary to make direct combustion, samples mostly being sent in coarse drillings. Undoubtedly they agreed with Mr. Snelus in this, that if they got a fine powder, well and good. They could do the combustion probably better from such powder by the direct combustion than by dissolving it in the double chlorides and burning the residue. In combusting ferro-manganese, ferro-chrome, and things of that kind, he invariably ground them into an excessively fine powder, which he then burnt directly in oxygen gas. But when they had very coarse drillings, such an operation was impossible, and then they were obliged to get at the carbon by some such method as had been described there. He would go home with very great interest to investigate methods of carbon determinations.

Dr. **Dudley** said it was hardly necessary to say much more than this, that they had succeeded in getting themselves into a condition where they really did not know where they stood. If any one had asked him six months ago to make a carbon determination of a piece of steel, and to testify in a court of justice that he considered the result reliable, he would have been perfectly willing to do so; but if to-day any metallurgist asked him how much carbon there was in a piece of steel, he could not tell. That practically was the state of affairs at the present moment. They had run across a possible source of error in one of their oldest and best established methods of chemistry. For nearly twenty years he had been working as a student, and later, the method which they were now using. This method had been taught by the most reliable schools, and was the very best they knew. Where the real difficulty was he could not tell them at present. Since the paper was written he had been continually experimenting in his own laboratory to find out where the error was. The double chloride of copper and ammonium made from commercial materials in one sample gave them 1·15 per cent., or rather 1·147 of carbon. The self-same materials were twice crystallised, and the second crystallisation gave them 1·052 per cent. carbon. The problem really was, Does the commercial material, without crystallisation in an acid solution, contain something that it ought not to have, or does the crystallised material dissolve some of the carbon when it is released from its embrace with the iron? He did not know. They had made these experiments since. It was well known by those who were chemists, that after they added the steel to the chloride of copper solution the result of the reaction was that there was a proto-chloride of iron present and a sub-chloride of copper.

Now, on the hypothesis that all commercial chlorides of copper contained a small amount of cellulose, obtained possibly from the filtering paper that might get into the solution during the commercial manufacture and dissolve—he said that on that supposition, if they took some commercial chloride of copper, or the salt made from commercial materials, and formed in it the same sub-chloride of copper and the same iron-salt, just the same as they would if steel was put in, the assumption was that the cellulose, if it was there, would separate out, and they would be able to catch it on the filter and burn it. They had made three experiments since the paper was written, on that hypothesis. One was by adding the sesqui-chloride of iron to a copper solution and reducing the salts with sulphurous acid. That experiment gave them an increase in weight of 3½ milligrammes. To account for the difference, they should have from 30 to 35 milligrammes. The second experiment was made with the same material which had been used in each of the experiments described in the paper by adding metallic copper to the double chloride solution. This would have resulted in the formation of the sub-chloride of copper (the same condition that they would have after adding steel minus the iron). That experiment gave them a little less than 3 milligrammes. But this would not account for that result. Furthermore, they had taken the double chloride solution, and treated it with sulphuric acid, the result of which would be to form the sulphates of copper and ammonium, and form free hydrochloric acid in the solution.

Now, if cellulose was not present, and if it was not soluble in the sulphate of copper solution, they ought to get it. That experiment was not finished a day or two before when he left Altoona. But the solution was as clear as any distilled water they had ever seen, or any solution they might wish to set eyes upon. Thus far, in their efforts to find the cause, they had not found it in cellulose dissolved in the double chloride, and they were still hunting for it. The chemists who were there had consulted together, and had planned a large amount of work to be done to hunt up this difficulty; so that he arrived at the point where he began—namely, that they were in a fog, as Mr. Stead had said. They did not know exactly where they stood. They would still make their best efforts to find the rogue, and hoped to come back to them with renewed confidence that their analyses were correct.

Mr. EDWARD RILEY said he would not enter into a discussion of the chemical part of the subject, because he thought it was very much better left to the chemists themselves. Being one of the Committee on International Standards, he might say that he thought all chemical questions were better referred to them. He could only testify to the very careful way in which the analyses had been made, and also that every possible precaution had been taken to avoid error; and yet with all that, there was a source of error which had cropped up, which had been discovered by those gentlemen, and which it would be the duty of chemists to investigate. He might say that in his own laboratory he did not buy his own chloride of copper. He roasted the copper scales and dissolved them in hydro-chloric acid, so that the inference would be that there could not be any cellulose in the chloride of copper that he used. He had had frequent communications with the largest steel-works in Germany, where they had operated upon precisely the same samples of steel, and also in England, and hitherto they had agreed. With regard to the remarks of Mr. Snelus, he thought that the gentlemen who read the paper, if they had had any confidence in the determination of carbon by direct combustion (this method, if it could be carried out practically, he was ready to admit, would certainly be the best method), would afterwards be ready to admit that it could be done only in occasional cases, and even then with considerable difficulty. Perhaps the gentlemen who formed the Committee would state their views, and Mr. Langley, he had no doubt, would give them his view upon the subject. He could not help thinking that if those five chemists, anxious as they had been to determine the percentage of the carbon by direct combustion, had evidence that they could determine the carbon accurately by that method, they would have done so.

Professor **Langley** said he had listened to the remarks which had been made upon his paper with a very great deal of interest, and he thought, speaking on behalf of the Committee, he might say they were very glad indeed of the suggestions which had been made. They would be very glad if still more could be made, and he trusted that other suggestions might reach them by letter. They were anxious only to arrive at the truth—the best method they could all agree upon. It seemed to him that that was so wide a field of work that the co-operation of chemists all over the world was necessary ultimately to settle so important a question in analytical science as that which was now raised. As to the remarks of Mr. Riley and Mr. Snelus about the direct combustion of steel in oxygen, he regretted to say his own experience was so limited that he would not venture to rest any statement upon it. He thought it was a very valuable process when carried out for research in scientific matters. He thought there could be no question that for a chemist engaged in the rapid work required in steel and iron works, or for commercial analyses, for any other purpose except scientific research, in which an unlimited amount of time could be taken, it appeared to him that the method by direct combustion was practically ruled out on account of the large amount of time and care necessarily involved in preparing the sample; and he thought it was Mr. Stead who called attention to the fact that the working chemist rarely received his sample in such a form that he could reduce it to the extremely minute and almost microscopic state of division which was necessary for the complete combustion of the carbon in the steel, when oxygen alone was used as the attacking agent. It seemed as though it was indispensable that the iron should be removed by some solvent before they could hope to rapidly and accurately determine the carbon. Therefore the question remained where it was placed at the beginning—namely, the necessity of seeking the co-operation of chemists all over the world in studying the vagaries of this method of steel analysis, determining where these vagaries arise and how they could eliminate them. The committee had listened to those remarks with very great pleasure, and he trusted they would all derive profit from what had been said there.

Dr. **Raymond** moved a vote of thanks to Mr. Langley and his associates for the preparation of the paper, and he did so all the more heartily because Mr. Langley was not a member of the American Institute of Mining Engineers, although well known to them all.

The resolution was carried unanimously.

The following paper was then read:—

AERIAL WIRE ROPEWAYS.*

BY J. POHLIG, COLOGNE, GERMANY.

It is with more than ordinary pleasure that I have complied with the request of the President of the Verein Deutscher Eisenhüttenleute to read before this meeting, and in this country, a paper on a system of transport by wire ropeways, which during the past twenty years has advanced with rapid strides in Europe, and more especially in Germany. America, with its immense network of railways and water communications, should offer peculiarly favourable opportunities for the introduction of these ropeways as feeders, more especially in the mining districts, where, as in Europe, a hilly or mountainous region frequently opposes serious obstacles to the employment of ordinary railroads.

The importance of the aerial ropeway as a factor in the development of mineral resources deserves the consideration of every mining engineer. As a case in point, the rich iron ore of the Sierra de Bedar, in Southern Spain, would probably remain untouched to this day but for an aerial ropeway, 15·6 kiloms. (9¾ miles) long, which connects the mines with the town of Garrucha, on the shore of the Mediterranean, affording cheap carriage to the nearest shipping port. A railway would have cost about $480,000 (£100,000), but such a heavy outlay would have more than absorbed all prospective profits on the sale of ore. As the aerial ropeway could be built for a little more than one-fourth that amount, $124,800 (£26,000), its erection furnished the successful solution of a profitable mining enterprise. This line has been in satisfactory operation for over two years. Its details will be referred to a little later.

But beside their importance as feeders, ropeways are valuable as a means of conveyance between works and distant warehouses, and between separate buildings in the same works. Their rapidly spreading introduction for such purposes indicates how keenly the necessity of effecting economies is felt under the stress of ever-accentuating competition.

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* Translated by Mr. R. E. Commans, London.

Ropeways have not been as generally adopted in America as they have in Europe, for the reason, I think, that thus far America's experience has been practically limited to the endless running-rope systems of Hodgson and Hallidie, which almost preclude continuous and regular working, and by which the weight of each single load is limited to 100 to 150 kilos. (2 to 3 cwts.).

By both of these systems one rope is employed, fulfilling the dual function of carrying- and hauling-rope for the buckets. Hallidie fixes his buckets to the rope; Hodgson, on the other hand, employs a saddle fitted with india-rubber, which grips the rope by friction, and is certainly an improvement. The simplicity and cheapness of these single-rope lines are at first sight very plausible; but yet their employment has been restricted. I believe the largest number of Hodgson lines in operation anywhere is to be found in Northern Spain, more especially in the iron ore district of Somorostro, near Bilbao. Two or three of these lines are at work there, one above the other, carried on the same supports. The drawbacks experienced in operating them, however, have been so serious that to-day the German double-rope system has almost entirely superseded the Anglo-American or single-rope system, despite the endeavours of the resident engineers to remedy its defects, which are:—

1. The slipping of the buckets in rainy and frosty weather.
2. The impossibility of working up steep inclines.
3. Great wear and tear of the ropes.
4. Frequent falling of the buckets in passing over the carrying pulleys.

The characteristic of the German system (of which Bergrath Freiherr Frans von Ducker is the father) consists in the employment of two ropes—a heavy fixed carrying-rope, and a light travelling hauling-rope. The buckets are fitted with special devices for gripping the hauling-rope. As is often the case with a new invention, a bad design of the details thwarted the satisfactory execution of the inventor's ideas, and as a result of the failure the system was regarded with very little favour in Germany some twenty years ago. Not until several years later, when Theodore Otto and Adolph Bleichert of Schkeuditz, near Leipzig, began to improve its mechanical details, did the doubts as to the merits of the system disappear. Since then, the demand for this class of ropeways has increased rapidly. In 1876 Otto and Bleichert dissolved their partnership, each continuing the business independently, and vieing with the other to perfect its features. My own firm, formerly of Siegen, now of Cologne and Brussels, has taken an active part in this competition—first as Mr. Otto's representative, but during the past ten years as a constructor of "Otto" ropeways for its own account. I have made a special study and business of the construction and manufacture of these ropeways, and have erected some of the most important lines now in operation.

Competition and ever-increasing demands upon this system of carriage have resulted in great improvements. Ten years ago loads of more than 200 to 250 kilos. (4 to 5 cwts.) were rarely transported, but at present it is not uncommon practice to carry loads of 400, 500, and even 1000 kilos. (8, 10, and even 20 cwts.), so that ropeways are now capable of conveying from 600 to 800 tons per day of ten hours. Just as marked as the increased carrying capacity of the lines has been the increase in their length: there are ropeways 10 to 13 kms. (6 to 8 miles) long, and one even of 16 kms. ($9\frac{3}{4}$ miles). These facts suggest that the active field for these lines can still be greatly extended. Practical men no longer look upon the ropeways as less safe or reliable than other means of transportation; hence in suitable cases, where they can be shown to operate with greater economy than other systems, they are given the preference, so that it is not surprising if since 1873 fully one thousand of these ropeway lines have been erected in Germany and other parts of Europe.

In the following brief description I shall dwell only on the most important features of the ropes, standards, and carriers.*

The *carrying* or *fixed ropes* are specially designed of stout steel wire 4 to 7 mm. in diameter ($\frac{5}{32}$ to $\frac{9}{32}$ inch), which has a breaking strain of 60 to 120 kilos. per square mm. (38 to 76 tons per square inch).

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* A numerous set of large and beautifully-executed drawings was exhibited by the author on the walls of the meeting-hall.

The *hauling-ropes*, on the other hand, in order to be as flexible as possible, are made with a hempen core and of fine steel wire, which has a breaking strain of 120 to 180 kilos. per square mm. (76 to 114 tons per square inch).

The *standards* which support the ropes are usually placed 30 to 60 meters (100 to 200 feet) apart. Larger spans are adopted only where the nature of the country requires it. Under special circumstances spans up to 500 meters (1640 feet) can be employed. The two-leg standard (figs. 1 and 2, Plate XXXIII.), which I was the first to introduce, is now the commonest form. When made of wood, the legs may be ordinary round poles, and the top cross-pieces consist of well-seasoned oak. If of iron, the uprights are usually constructed of channel or I-beams stiffened with angle-iron, and the cross-pieces are made of channel-iron. Where heavy loads and great spans are necessary, four-leg standards are employed (figs. 3 and 4, Plate XXXIV.).

The *carriers* are of various designs, to suit their particular service. For coal, ore, stone, and similar material, sheet-iron buckets (fig. 5, Plate XXXV.) are used with special provisions to tip them easily. For the conveyance of bulky goods, special forms of carriers (figs. 5 and 6, Plate XXXV.) are designed. For timber, boards, bar-iron, tubes, &c., two carriers coupled together usually answer.

An important feature of the carrier is the truck or runner (fig. 7, Plate XXXVI.). This form has been in use for over six years, and has entirely overcome the faults of the earlier design, in which the spindles of the grooved wheels were supported on one side only. By supporting them on both ends, wheels are not liable to assume an oblique position, and the carriers are bound to hang always vertically. The frame of the truck consists of two steel plates connected in the middle by a cast iron distance-piece, through which the spindle of the hanger passes, and at each end by a phospher-bronze distance-piece, which forms the spindle for one of the grooved wheels. Each of these spindles is hollowed out to contain a lubricant, which is inserted by removing the thumbscrew shown in the end. The lubricant passes through small holes to the surface of the spindles, and this automatic lubrication is so perfect that both spindles and rollers are preserved from almost every sign of wear, even after several years' use.

Another equally important detail, to ensure regular and uninterrupted working, is the form of coupling or grip for attaching the carrier to the hauling-rope. This must be not only simple in design, but also absolutely reliable in its action, and should reduce the wear on the hauling-rope to a minimum. The so-called friction-grip, and the lock-grip, are the usual types employed. With the former, the carriers can be attached to the hauling-rope at any point; with the latter, small collars or carrier-knots have to be fixed at intervals along the hauling-rope, corresponding to the distance apart at which it is intended to attach the carriers.

The form of friction-grip employed by us for the past twelve years, and now most generally used (fig. 8, Plate XXXVI.), consists of two smooth-faced discs, one rigidly attached to the cross-bar of the hanger, and the other mounted loosely on a spindle and free to revolve, acting when necessary as carrying-roller for the hauling-rope. The spindle has a square thread on its outer end, and carries a lever, the boss of which forms the nut. When the lever is down, the discs do not grip the rope, but are kept apart by a spring. As it is raised, the discs approach each other, and when up, the hauling-rope is tightly gripped. The lever is prevented from falling back by a small spring-trigger. As the carrier-bucket approaches a station, both the lever and trigger encounter a stop, which throws them over, separating the discs, and automatically releasing the hauling-rope. The bucket is then free to be switched off the carrying-rope to a siding. The discs can be easily adjusted, allowing for the size and wear of the rope. This form of grip is employed for gradients up to 1 in 6, and for loads of 450 kilos. (9 cwts.) net weight.

For steeper gradients, up to 1 in 3, where a friction device is still practicable, a more powerful grip, with corrugated jaws, (fig. 9, Plate XXXVII.) is used, instead of the smooth-faced discs. One of the jaws is rigid; the other is moved in and out by means of a lever and cam, so as to grip the hauling-rope.

Both forms of friction-grip have given satisfaction. Since the buckets can be attached to the hauling-rope at any point, the tendency to a uniform wear throughout the length of the rope is promoted, and this is a distinct advantage.

For lines having gradients under 1 in 6 the disc-grip is doubtless the better form; as it subjects the hauling-rope to the least wear. As an indication of how little the rope really suffers, I might mention the Fernie ropeway erected in Giessen in 1879, where the original hauling-rope is still in regular use, transporting 300 to 350 tons of ore per day. Another advantage of the friction-grip is that by its use it is easy to alter the carrying capacity of the line simply by adding more carriers at shorter intervals, without varying the travelling speed of the hauling-rope.

For gradients greater than 1 in 3 a lock-grip of some kind is absolutely necessary. The number of buckets and the corresponding capacity of the line for a given speed are then limited by the spacing of the knots on the hauling-rope. The design of the knot is of great importance—almost as vital as the design of the grip itself. Simple as the present form of knot appears, it would occupy several hours to describe the various designs that have been tried and cast aside. The star-section knot which is now used surpasses anything known before for the purpose. Its special advantages are:—

1. Quick attachment to the hauling-rope without opening the latter.
2. Attachment to the hauling-rope without the use of babbit-metal or soldering.
3. Preserving the full flexibility of the hauling-rope at the point of attachment.
4. Prompt detection and easy repair on any breakage of single wires.

Improvements in the form of the couplings or grips have kept pace with improvements in the knots. The earliest design of a lock-coupling was a complicated clockwork full of springs and levers, which were ever getting out of repair. The pawl-grip (fig. 10, Plate XXXVII.), which I have used for several years, is the perfection of simplicity, and never fails. It consists of two symmetrically disposed pawls, each free to move in a vertical plane, and having forked ends which drop down on either side of the knot, the drop being checked by a stop. The rope is supported on a roller just below the pawls. To throw the pawls in and out of action, the toe of each pawl carries a pin which engages with a guide-rail at the station. The process of coupling a bucket fitted with one of these grips to the hauling-rope is as follows:—The workman moves the bucket by hand along the switch-rail to the carrying-rope; on approaching this, the pawl-pins come in contact with the guide-rail, raising the pawls so as to allow the hauling-rope to be guided and rest on the roller which is immediately below them, and forms part of the grip. As soon as the bucket rests on the carrying-rope, the pins are released from the guide-rail, and the pawls fall down in position over the hauling-rope. As a knot approaches, it lifts the first pawl, which, however, falls back into its original position; but the second one resists, and the bucket is automatically taken in tow. To avoid a violent impact of the knot upon the coupling, the shunter gets a bell-signal when a knot is approaching, and he pushes off the bucket at about the same velocity as the rope is travelling. The uncoupling is similarly effected. As the bucket nears the station, the pawl-pins come in contact with a guide-rail, lifting the pawls out of gear, and releasing the hauling-rope; the bucket by virtue of its momentum then moves off the carrying-rope, and up a tongued rail, which switches it to a siding. This is the only lock-coupling to my knowledge that is thrown in and out of gear automatically.

With many of these pawl-grips now at work, I do not recall a single instance where a carrier has become uncoupled on the journey. I employ this grip exclusively on all mountain lines, and have used it in safely transporting loads of more than 1000 kilos. (1 ton) up gradients of 1 in 1.

Description of Some Ropeway Lines.

Garrucha Line.—The most important ropeway yet constructed is the one I have already alluded to, for the transport of iron ore in Southern Spain from Serena de Bedar to Garrucha. This line (figs. 11 and 12, Plate XXXVIII.) is 15·6 kms. (9·69 miles) long, and divided into four independent sections, with lengths of 2·4, 3·4, 5·3, and 4·5 kms. (1·49, 2·11, 3·29, and 2·8 miles) respectively. A 30 horse-power engine drives the first two sections, and a 70 horse-power engine the last two.

The line, after leaving the loading-station at Serena, 276 meters (905 feet) above the sea, crosses a number of deep valleys, one nearly a kilometer (upwards of half-a-mile) wide, and 100 meters (328 feet) deep, and traverses mountain ridges, the highest of which is 358 meters (1174 feet) above sea-level, to the village of Pinar de Bedar, where, at an elevation of 290 meters (951 feet), the first engine-station is located. From here the line deflects to the right, and again passes over several valleys and ridges, with a gradual descent to a second angle-station, 118 meters (370 feet) above sea-level. It then bears to the left, extending over a more or less hilly country to the second engine-station (figs. 13 and 14, Plate XXXIX.) at an elevation of 45 meters (147 feet). From here it again turns to the right, descending at a comparatively easy gradient to the unloading station on the coast, near the town of Garrucha.

Standing on the mountain ridge between Bedar and Serena, where the line can be traced from end to end, the prospect is imposing, 660 buckets travelling back and forth, growing smaller in the distance until they seem but mere faint specks, and the ropes brightly reflected in the sunlight, looping in the sea with a silvery cord. The capabilities of the system are nowhere more strikingly exhibited, and the precision with which the carriers move and deliver their loads heightens the effect.

The greatest span of the line near the Villa Reforma is 280 meters (918 feet). In this plan the rope sags 20 meters (65 feet), and carries six loaded and six empty buckets at a time. Its height above the valley is 50 to 60 meters (164 to 196 feet). The other long spans of the line range from 100 to 225 meters (328 to 750 feet), but the average distance between the supports is only about 40 meters (130 feet). The steepest gradient, taking into account the sag of the rope, is 1 in 2½, and the tallest standard is 36 meters (118 feet) high (fig. 11, Plate XXXVIII.). The guaranteed capacity of the line is 400 tons per day of ten hours. With a travelling rate of 1·5 meters per second (300 feet a minute, or about three miles an hour), and with two buckets of 350 kilos. (7 cwts.) capacity arriving every minute, or 1200 buckets per day of ten hours, the actual quantity carried by the line is 420 tons, making its capacity 6552 ton-kiloms. (4095 ton-miles), which, so far as I know, has not yet been equalled by any other line. Owing to the increased demand for Bedar ore, the line has been worked since the commencement of 1890 in two shifts of eight hours, and no less than 900 tons per day have been transported to the coast.

The carrying ropes for the loaded and unloaded side, respectively, are 33 and 26 millimetres ($1\frac{5}{16}$ and 1 inch) in diameter, and the size of the hauling-rope is 18 millimetres (about $\frac{3}{4}$ inch). The latter is fitted with the star-section knots above referred to. The pawl-grip previously described (fig. 10, Plate XXXVII.) is employed throughout.

At the loading-station bins of 800 tons capacity are erected from which the ore is spouted into the buckets. The engine and boiler houses are solidly built and large enough to be used as repair-shops. Great care has been bestowed on the design and arrangement of the driving gear and engines (see figs. 13 and 14, Plate XXXIX., representing the second engine-station near Puerto del Coronel).

The unloading-station on the coast is 46 meters (150 feet) long by 15 meters (50 feet) wide, and 10 meters (32 feet) above the ground-level. Its storage capacity is 18,000 to 20,000 tons, so that four to six vessels can be loaded at a time.

At the various stations sidings are arranged for docking empty carriers of the several sections of the line. Electric signals are used, and the stations are connected by telephone. Despite many difficulties, the line was surveyed, erected, and ready for work within ten months, its total cost amounting to $124,800 (£26,000).

At the desire of the mining company, I undertook to work the line for a number of years at the rate of 1·50 franc (28·8 cents) per ton carried, this price covering all costs for labour, maintenance, and repairs.

Völklinger Line.—The second line which will be of special interest is at the Völklinger ironworks. It serves to convey slag across the River Saar to a waste-dump, and to carry back coal from a neighbouring colliery for use in the rolling-mills. The plant consists of three intercommunicating lines, as shown in the general plan, Plate XXXII., right side:—The blast-furnace line, the rolling-mill line; and the Hostenbach line.

Their aggregate length is about 3·3 kms. (2 miles), and they are driven from one central station.

The blast-furnace line for the removal of slag passes through an underground tunnel, in order to leave the space around the furnaces free. Suspended rails are used in its construction, in place of the customary wire carrying cables. Before delivery into the buckets, the slag from each furnace is granulated and collected in a large iron receiver, which has a perforated false-bottom (see arrangement of slag-receivers, Plate XXXII.). Receivers have been built of 100 and 200 cubic meters (3230 to 7060 cubic feet) capacity, or sufficient to hold all the slag produced at night, so that the rope-line has to be operated during the day-turn only. Each receiver is divided by a partition, allowing one side to drain while dried sand is being loaded into buckets from the other. The buckets are filled from spouts placed around the bottom of the receivers, and fitted with sliding gates. The receivers are covered in on the ground-level with a strong iron grating, so that the workmen can pass over them without let or hindrance.

This method of granulating and removing the slag without the employment of elevators, &c., I used for the first time in 1882–83 in connection with the ropeway at the Johanneshütte, near Siegen. It has since met with great favour in Westphalia, where a number of works have adopted it, even among those who at first were strenuously opposed to granulating, because of the greater space occupied by slag-sand than slag-blocks. It cannot be denied that the quicker filling up of the dump which results from granulating the slag is in many localities a serious drawback; yet the advantages of this system over the costly haul of solid or liquid slag will often more than off-set the objection—aside from the consideration that ropeways afford a means for piling the waste-dump to any desired height, or, if suitable dumping ground does not exist near the furnaces, for transporting it any desired distance—possibly to fill in old quarries, or level up waste land. Many attempts have been made to adapt this method of transport to solid slag—the slag being run into specially designed buckets, and allowed to solidify, but in every instance such efforts have ended in failure. I tried it on a large scale at the Niederschelldener ironworks, near Siegen, but was eventually obliged to give it up because I could not make sufficiently durable buckets, either of cast or wrought iron, or steel. To line the buckets with fire-brick would have made them too heavy. I can, therefore, confidently recommend the system of granulated slag transport as the simplest and cheapest, provided that local conditions permit the use of a low-level loading-station, and favour an easy drainage of the water.

The rolling-mill line is carried above the mill to an iron scaffold 9·4 meters (30 feet) high, the unloading station for coal, situated in front of the puddling-works. Below it are seven large iron pockets of 500 tons total capacity, into which the coal is dumped from the ropeway buckets. When coal is required in the works, it is drawn from the pockets by means of sliding gates, and delivered by light portable railway trucks.

The main line to Hostenbach for the further conveyance of the slag, and the return transport of the coal (see the general plan, Plate XXXII.), crosses the railway line and River Saar to the top of a wooded hill, 30 meters (98 feet) high, on which a dumping-station 19·6 meters (63 feet) high has been erected (Plate XXXII., left side). This serves at the same time as an angle-station for the extension of the line to the Hostenbach colliery. The loading station at Hostenbach consists of two large bins, each of 100 tons capacity, fitted with six spouts for loading the ropeway buckets (Plate XXXII., left side).

All three lines are driven by one 40 horse-power coupled engine, the power being transmitted by a belt and friction-clutch. Each line is so arranged with switches that the buckets can be run from one to the other without difficulty. Moreover, if it is not necessary to carry back coal from Hostenbach, the slag-trucks arriving at the dumping-station are emptied, and then passed through the station and recoupled to the river branch of the line, as indicated by the dotted curve in the plan of the station (Plate XXXII., left side).

The main line is designed to carry 500 tons of slag to the dump, and 300 tons of coal to the mill. As a rule, two buckets of 400 kilos. (8 cwts.) capacity arrive in each minute, travelling at a velocity of 1·5 meters per second (300 feet a minute). They are, therefore, 45 meters (150 feet apart), and on an average 1200 loaded buckets are carried per day of ten hours.

The diameters of the carrying-ropes for the main line are 38 and 30 mm. ($1\frac{5}{16}$ and $1\frac{3}{16}$ inch). Those for the Hostenbach and rolling-mill lines are respectively 30 and 25 mm. ($1\frac{3}{16}$ and 1 inch). The hauling-rope is of one size throughout, namely, 15 mm. (nearly $\frac{5}{8}$ inch) diameter. The gradients are easy, and disc-grips are therefore used.

All the standards are of iron except on the slag-dump, where wood trestles are used, and are allowed to be buried under the accumulating slag. The design, which has already been shown in fig. 2 (Plate XXXIII.), was first introduced by me in 1881.

The standards on both banks of the Saar, however, are of the four-legged type, 19·84 meters (65 feet) high, as the river-span is upwards of 100 meters (328 feet).

The general method of operating the plant is as follows:—The empty buckets at the power-station are coupled to the hauling-rope at the point *A* (see plan of power-station, Plate XXXII.), and travel into the tunnel, where they are automatically disengaged in front of any one of the receivers. When the buckets have been filled, they are again coupled up to the hauling-rope, and on reaching the point *B*, are automatically uncoupled and shunted round on the hanging-rail *s*, to the point *C*, on the main line, along which they travel to the angle-station, where at the point *D* (see station for slag-dump, Plate XXXII., left side), they are shunted off on the hanging-rails, *s*, *s*, and the slag is dumped.

The empty buckets are then pushed round to the point *E*, coupled to the hauling-rope and despatched to the colliery. Arriving at *F* (see loading station at Hostenbach Mine, Plate XXXII., left side), the buckets are filled with coal from the bins, pushed round to the point *G*, and started back, passing *H* and *I* in the angle-station, and reaching the central station at *K*. From here the buckets are moved round to *L*, and pass over the rolling-mill line to *M* (see unloading station on the rolling-mill line, Plate XXXII.), and thence along the hanging-rail, *S′ S′*, to the coal-bins, into which the coal is tipped. The empty buckets are then pushed to the point *N*, and despatched back to the central station. On arriving there at *O*, they are shunted round to the starting-point *A*, and thus the circuit is completed. If no coal is wanted from the mine, all that is required is to throw in the switches, *w*, *w*, at the angle and central stations, in order to short-circuit the line.

For the removal of ashes and rubbish, short lines are used, which can be connected with the central station. When all the sections are in operation, twenty-two men are required.

At the central station: one engine-driver, three shunters for coupling and uncoupling the buckets, one man for moving the trucks.

In the tunnel: two shunters for loading and coupling up the buckets.

At the angle-station: two shunters and three men to move and tip the trucks.

At the colliery: two men to shunt and one to load the trucks.

At the rolling-mill station: two shunters and one man to unload.

For the plant in general: one inspector and two fitters.

The line has been worked continuously since 1889, and has given great satisfaction.

Rumelange Line—This was the first double aerial line erected and used to charge blast furnaces directly. The general features appear in fig. 15 (Plate XL.), and the charging arrangement in fig. 16 (Plate XLI.). Iron ore is carried direct from the mine to the top of the furnaces.*

Marienhütte Line—At these works, which are situated near Siegen, in Western Germany, a line is employed for carrying iron ore from the mines to the furnace plant, and returning the slag to the mine for back-filling. Fig. 17 (Plate XLI.) shows the profile, and figs. 18 (Plate XL.) and 19 (Plate XLII.) the loading and unloading stations for the ore.

Aiseau-Presle Colliery Line—This line, near Farciennes, in Belgium, derives special interest from the fact that the mine cars themselves are carried over the line, instead of ordinary buckets. The weight of each loaded car is 900 kilos. (18 cwts.), and the amount of coal transported daily is 800 tons.

Lines in the Transvaal—Ropeways are now being introduced into the Dark Continent for the transport of gold quartz. Four lines have already been determined on for the Sheba, Edwin Bray, Oriental, and Amsterdam Gold Mining Companies. Two of these are now completed. The nature of the region traversed is shown by the profile (fig. 20, Plate XLII.), which offers a further illustration of the peculiarly favourable adaptation of these aerial rope-ways to a very difficult broken country.

In conclusion, gentlemen, I trust that what I have now brought to your notice may decide you to make a trial of these aerial ropeways, and lead to their introduction into this country. I am sure that my fellow-countrymen and colleagues, equally with myself, esteem it an honour to be able to introduce to your notice something of a practical nature in return for the many great and practical improvements you have sent us across the water.

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* For a full description see *Zeitschrift des Vereins Deutscher Ingenieure*, vol. xxxii. p. 1045.

DISCUSSION ON MR. POHLIG'S PAPER.

Dr. **Raymond** said he did not care to take up the time of the meeting by discussing this question, except to express his pleasure that Mr. Pohlig had brought before them the interesting details of his system, and to correct the misapprehension under which he seemed to labour, that the system was unknown in that country, and that he brought it to them as a thing of the merits of which they still had to be convinced. He only said that in the name and place of Mr. E. G. Spillsbury, who would have replied to the paper in New York if it had been presented there, as was expected. Mr. Spillsbury was the general manager of the Trenton Iron Company, of which he (Dr. Raymond) was consulting engineer, and he had been engaged for some years in the erection of aërial wire-rope tramways on the Bleichert system, which, with some details of difference, was essentially the same thing as that of Pohlig and Otto. Bleichert and Otto, as Mr. Pohlig had said in his paper, were formerly partners, and they based their respective details upon a fundamental principle, which was, that instead of having a triple rope, as was the case in the Hallidie tramway and the Hodgson tramway, there was a stationary rope, and then a light moving rope, which did not carry any weight. That was the fundamental difference between those excellent tramways and the previous English forms of Hallidie and Hodgson, which were far less durable. The Bleichert system was controlled in America by 29 companies, and had been erected during the last few years in large numbers. They would see a good example of it at the works of their fellow-member, Mr. Cogswell—that was, those of them who went on the Northern trip, as Mr. Pohlig had told him he would have the pleasure of doing.

He would call attention to this fact, that on their return from the North, if they went by Niagara Falls on the Central Road, the cars passed under one of those tramways at Syracuse—he thought about a mile long. Several hundred tons of limestone were moved from the quarries to the works at Syracuse. They had also erected several large tramways of that kind, several miles in length, in Montana, on the granite mountain mines, and they had erected a large system of those tramways in the celebrated mining district of Aspen, in Western Colorado, where their Institute of Mining Engineers held a meeting two years ago. They were delivering from all points on the mountain to a common centre at the mill by means of a wire-rope tramway the product of the mine. They had also erected tramways of this kind for the handling of slag; and they had put up one in Cuba, which was to bring 200 tons of bananas a day, and load them into a ship in the open roadstead. That was a peculiar construction, involving the same principle, but carried out to sea on floats, because there was no harbour there, and the tramway came down a steep mountain bluff—so steep that there could be only a mule trail made before—and then went out to sea on the floating piers, and had a terminal out in the open roadstead. When the wind was so unfavourable, or if it was stormy, the ships sailed away, and the tramway closed or shut up against the floating piers, so that the outer wing of it was adjustable, shutting up in stormy weather, and spreading out again when the weather permitted the loading or unloading of the bananas. Mr. Pohlig would see, therefore, before he left the country, that they had appreciated the system, and that they were doing their best to introduce it for the various purposes to which it was applicable as a means of feeding railroad lines, and as a means of transportation on branch lines down to the main points, where the freight could be taken by the railroad. It was in his judgment an important thing. They had now in several States laws permitting the corporate organisation and acquisition of land for such tramways; and so far as the cost of running was concerned, Mr. Pohlig would be glad to know that they were handling freight by those tramways in that country for about two cents per ton per mile, if the traffic was over 100 tons a day.

A vote of thanks was tendered to Mr. Pohlig.

PRESENTATION OF DRAWINGS, &C.

Dr. **RAYMOND** said he desired to say, before the Session was brought to a close, that a large part—he could not exactly indicate to them how much, but a very large part—of the drawings and samples there, including the specimens or samples of Mr. Thielen, and nearly all the drawings exhibited by Dr. Wedding, had been placed by those gentlemen at the disposal of the Institute, and upon his suggestion they were to be presented at the close of that Session to the American Society of Western Engineers, which had its headquarters in Pittsburgh, as a testimonial on their part, and of the authors also, to the courtesy and hospitality with which the Engineers of the West have received them in Pittsburgh; and as a testimonial also that there was no better place than that centre of the iron metallurgy of the country for depositing those evidences of the metallurgy of other countries. He called on Professor Langley, who was a member of that Society of Western Engineers, to acknowledge the gift.

Professor **LANGLEY** acknowledged with very much pleasure that very graceful gift which the Institute had just made to the Western Society of Engineers. He regretted very much that their President was not present to discharge the duty of receiving the donation. But he was sure that he spoke the sentiment of all its members when he said that it would give them the utmost pleasure to place those drawings and those articles in their library, and to derive from them the instruction which they contained, and to place them, as far as lay in their power, before the public, for their instruction as well.

The proceedings then terminated.

The following paper was taken as read, and distributed at the meeting.

THE IRON ORES OF THE UNITED STATES.

By T. STERRY HUNT, M.A., LL.D., F.R.S., New York City.

Having been honoured by a request to prepare for this occasion some account of the iron ores on which a great industry has been built up in the United States, and, moreover, to make such a record of our present knowledge as may be of value alike to our distinguished guests from abroad and to my colleagues of the American Institute of Mining Engineers, I had at first some doubts how best to approach the task. That among my hearers are many better fitted to discuss the question of our iron ores from commercial and economic points of view I am well aware; but I have thought that my studies, chemical, mineralogical, and geological, continued during a period of more than forty years, and covering a wider field than those of any other observer, would enable me to present the theme under a somewhat novel aspect, and, moreover, to connect it with geological and geographical facts which will give to the description a permanent value. To this end, it is evident that the great coalfields and their relations to the iron ores of the more ancient rocks have to be carefully kept in view.

Over nine and a half million tons of pig iron were produced in the United States during the year ending June 30, 1890, including about half-a-million of tons from imported ores. Of the nine millions, in round numbers 99 per cent. were made from ores mined to the east of the Mississippi, and the remainder, with insignificant exceptions, in the State of Missouri, near the western bank of that great river. The supply of native ores is, therefore, essentially from the eastern portion of our country. From the Mississippi stretching westward to the frontier range of the Rocky Mountains, and in that great mountain-range itself, are treasures alike of iron and coal which await development; while still farther west, the vast American basin and its Pacific mountain-belt have as yet attracted attention chiefly for their rich stores of gold, silver, copper, and mercury.

Up to the present time, then, it may be said that the iron industry of the United States is confined to the great region drained by the Mississippi and Ohio and their tributary rivers southward toward the Gulf, by the northern chain of lakes discharged by the St. Lawrence, and to the Atlantic mountain-belt, whose drainage waters find their way by more direct channels to the Atlantic. The great physical features of this eastern half of the North American continent are remarkable. Between the eastern front of the Cordilleras in Colorado, and the mountains of the Atlantic belt, and the Appalachians, which stretch from New England and eastern New York to Alabama, spreads a vast region, traversed by navigable rivers, from Lake Superior southward to the Gulf of Mexico, and eastward to the Gulf of St. Lawrence. In one place alone is the great Atlantic barrier broken. This is where the tidal and navigable waters of the Hudson River pass through the Highlands, and, permitted by the sinking away of the Appalachians in southern New York, connect the waters of the Hudson, through the Erie Canal, with those of Lake Erie, and through Lake Champlain with the St. Lawrence, affording a system of internal navigation which must always give to the city of New York a commercial supremacy on our eastern shores.

Geologically speaking, the structure of this great interior region is as simple as it is geographically. Nowhere, perhaps, in the Old World are the areas of the principal geological groups so widely extended; nowhere else are displayed such large and accessible coalfields. The ancient crystalline rocks which, while they constitute the Atlantic belt, skirt the northern borders of the great lakes and the St. Lawrence valley, and to the westward form the range of the Cordilleras, are rich in valuable iron ores. Small areas of these older iron-bearing rocks rise like islets among the younger strata in Missouri and in Texas; while the great Appalachian valley, itself abounding in ores of iron, stretches along the western base of the Atlantic belt, which it divides from the parallel Appalachian or Alleghany mountain-range. The coal-measures themselves in various parts of their distribution, moreover, abound in ores of iron.

Without here entering into details, it should be said that the important coal-basins of the region in question are all of Paleozoic age; the small basins of newer coals in eastern Virginia, North Carolina, and farther westward being of little account in the present connection. In like manner, the iron ores of the region may be said to be Paleozoic, or still more ancient. The extensive areas of Mesozoic and Cenozoic rocks in our territory, so far as known, furnish little or no iron ore; the small portions of Tertiary strata with lignite, ochres, and hydrous iron ores, at intervals from Vermont southward along the Appalachian valley, being of geological rather than of economic interest. In the early days of our history small deposits of bog ore were wrought in many places, but have long since lost their importance. Mention, however, should here be made of the magnetic iron-sands, which have a certain historic interest. Found along the shores of Connecticut, the sands early attracted attention in England under the name of the American sand-iron, and in 1763 were noticed alike by the Royal Society of London and the Society of Arts. The sand was even manufactured into malleable iron in a furnace on the Connecticut coast, which was probably a German bloomery. Attempts to work similar sands in the Gulf of St. Lawrence and on Long Island, New York, have been made in our time without pecuniary success.*

Passing over these preliminaries, we may now proceed to describe the principal iron ore horizons of the United States in geological succession, beginning with those of the ancient crystalline rocks which, as they underlie the Paleozoic, have been variously designated as Eozoic, Archæan, and Primary. These rocks, as the result of lifelong studies, we have been led to divide into several distinct groups or terranes, which appear to have a definite order in the earth's crust, and, moreover, to sustain constant relations to their contained iron ores; thus giving to these divisions not only universal application, but great economic importance. Without entering at length into questions of theoretical geology, it may be said in a few words that we reject for these ancient crystalline rocks alike the so-called metamorphic and the igneous hypotheses of their origin, believing them to have been formed at definite and distinct periods in the world's earlier history, through the intervention of water, but under conditions widely different from those of later sediments.[*] We, moreover, reject as untenable the notion of the igneous origin of the iron ores themselves, which appear to be in all cases deposited from water, generally contemporaneous with the enclosing rocks, but more rarely by subsequent processes in fissures, after the manner of mineral veins.

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* Those who are curious to follow the details of this history will find it told at length by the writer in the Report Geol. Survey of Canada, for 1867-69, pp. 261-269, 280-284. See further, J. M. Swank, *Iron in All Ages*, p. 97, for the early trials in Connecticut.

The great divisions of these stratiform crystalline rocks are designated as follows in ascending order: Laurentian, Norian, Arvonian, Huronian, Montalban, and Taconian.[†] The succession is, however, frequently incomplete from the local absence of one or more of the intermediate divisions. The first of these divisions, named from the Laurentide Mountains north of the St. Lawrence, includes also the greater part of the Adirondacks, the Highlands of the Hudson, and the continuation of these along the so-called South Mountain or Blue Ridge, into the Carolinas. We have predominant in this terrane a peculiar type of granitoid gneiss, with highly inclined stratification, sometimes associated with crystalline limestones in certain portions, and including in beds and lenticular masses conformable to the stratification great deposits of iron ore, generally magnetic, which are extensively mined in the Adirondacks to the west of Lake Champlain, and farther southward at intervals along the Atlantic belt at least into North Carolina. To this most ancient horizon also belong the similar rocks and ores in Canada, to the north of the St. Lawrence and of Lake Ontario.

These Laurentian magnetites are sometimes exceedingly pure, but at other times they include phosphate of lime, which, in the form of crystalline apatite, marks, in one locality on Lake Champlain, the planes of stratification of the ore. This impurity, however, is of rare occurrence. Iron pyrites are not infrequently so abundant as to render a preliminary roasting of the ore necessary, and combined titanium oxide is sometimes found, though not, so far as known in this terrane, in such amount as to unfit the ores for use in the blast-furnace. The occasional occurrence of disseminated scales of graphite in these Laurentian magnetites is a fact of mineralogical interest, and the presence of intermingled calcite, quartz, orthoclase, pyroxene, and other silicates, notably a chloritic mineral, may be noted. Crystalline specular hæmatite sometimes replaces the magnetite in these Laurentian rocks. Mention may here be made of franklinite, a mineral resembling magnetite, but including, besides the oxide of iron, those of manganese and zinc. It is, moreover, generally accompanied by crystalline red zinc oxide. This ore, elsewhere a mineralogical rarity, is mined to some extent in the Laurentian in New Jersey, and after yielding its zinc by distillation, is smelted, yielding a magnesian alloy or spiegeleisen.

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[*] An extended statement of the writer's views on this subject will be found in an "Essay on the Origin of Crystalline Rocks and the Crenitic Hypothesis," in his volume entitled *Mineral Physiology and Physiography*, pp. 68–189; Eds. 1886 and 1890.

[†] *Mineral Physiology and Physiography*, pp. 403–425; also Report E, Second Geological Survey of Pennsylvania, *passim*.

Next in ascending order among the Eozoic terranes we have placed the Norian series, so called from the predominance therein of great masses of stratiform norite, a rock essentially composed of labradorite or some closely related feldspar. These norites are, however, not unaccompanied with gneisses and limestones like those of the older Laurentian, on which the Norian is found to rest unconformably in many localities. So far as is known, the iron ores of this series are highly titanic, and though sometimes holding an admixture of magnetite, are often destitute of magnetism, being a pure ilmenite or menacannite, and in some cases containing an excess of titanic oxide in the form of crystalline grains, apparently of rutile. These ores, though sometimes abundant, are thus, in the present state of our iron industry, of little value. They abound in areas of Norian rock in the Adirondack region in Essex county, New York, and have been found under similar conditions in the Black Hills of Wyoming and in various parts of Canada, notably at the Bay of Seven Islands, on Lake St. John, and at Bay St. Paul, near Quebec, where an unprofitable attempt was made to smelt them a few years since. Similar ores are found in the Norian rocks in the isle of Skye, and in Norway, in which country and in England they have been smelted to some extent, when not too titaniferous, in admixture with other ores, or else with great addition of amounts of flux. The magnetic ores of Scandinavia occur, so far as is known, in a gneissic series, apparently identical with the Laurentian.

Third in the ascending series of crystalline terranes we have placed the Arvonian, which may be described as a stratified petrosilex, either jaspery or porphyritic in character, apparently the same with what is called hälleflinta in Sweden, and associated with quartzites, certain argillites, greenish fine-grained schistose rocks, and more rarely with crystalline limestones. To this horizon belong the remarkable varieties of magnetite and red hæmatite mined at the Iron Mountain, Shepherd's Mountain, and Pilot Knob, in Missouri. I have examined areas of these same rocks in Wisconsin, along the north shore of Lake Superior, in the crystalline belt known as Green Ridge to the west of Gettysburg in Pennsylvania, and at many points along the New England coast, from near Boston to the Bay of Fundy, and farther east in the Cobequid Hills; noting occasionally the occurrence of iron ores like those of Missouri, which at points in Maine and in Nova Scotia may assume an economic importance. This series, which was included by C. H. Hitchcock in the base of the Huronian, is also well developed in Sweden and in North Wales, where it was designated by Hicks as Arvonian.

Passing over the Huronian proper for a moment, only to return to it again, we notice the great terrane, which includes the younger gneisses, and the fine-grained granulites and mica-schists of the White Mountain series, which we have designated Montalban. Widely developed in New England, it underlies the city of New York, there resting directly upon the Laurentian gneiss of the Highlands, which is itself seen in the northern parts of the city. The Montalban is well displayed in and around Philadelphia, and forms a large portion of the Blue Ridge throughout its southern extension. Remarkable for granitic veins sometimes carrying tin and other rarer elements, the Montalban abounds in many parts with deposits of iron pyrites, often cupriferous, but is not rich in iron oxides, though including in some localities beds of magnetite.

The Huronian series itself demands special notice, because great deposits of certain iron ores, now believed to belong to the distinct Taconian or Taconic series (about to be considered at length), were for a long time referred by geologists to this horizon. The Huronian, a great terrane marked by characteristic serpentinic, dioritic, chloritic, and epidotic rocks, and including important deposits of sulphuretted copper ores, contains, it is true, more or less hæmatite and magnetite, in some cases at least with considerable admixtures of titanium, and also carries chromic iron ores, which in various parts of its distribution are of economic importance. The immense deposits of magnetic and specular iron ores in the vicinity of the great lakes, in rocks formerly called Huronian, are, however, to the best of the writer's judgment, to be referred to the Taconian.

The study of this series brings us back to the eastern part of the United States, and to the region already defined as the Appalachian valley, lying along the south-western border of the great Atlantic belt, and traceable from western Vermont as far southward as Alabama. From an early time in the history of American ironworking, the importance, as a source of iron, of the brown ores of that region was recognised, and they were smelted more than a century since in western Connecticut and in Pennsylvania. These hydrous ores, for the most part limonite, and generally known as brown hæmatite, are found imbedded in soft deposits, more or less clay-like in character, and consisting of certain crystalline schists altered and greatly softened *in situ* by chemical changes, often to a depth of 100 feet or more. These folded and inclined strata, which have been sheltered from erosion by the belt of older crystalline rocks along their border, merit an especial study, alike for themselves and for the ore-deposits which they include. The similarity in form, distribution, and mode of occurrence of these hydrous ores is well known to those engaged in the mining of them, and may be advantageously studied in parts of western New England and in Duchess County, N.Y., in portions of New Jersey, and throughout the great Appalachian valley in Pennsylvania and farther southwards, where they are also associated in many places with anhydrous oxydised ores—magnetite and red hæmatite. The nature of all these deposits, but especially of the hydrous ores and their decayed strata, as well as their geological age, has been the subject of much vague speculation, and unfortunately of great misconceptions, on the part of many geologists; nor is it too much to say that an adequate solution of the problems thus raised involves many difficult questions alike of chemistry, of mineralogy, and of geological stratigraphy, which go far to explain the confusion still existing, and which we shall endeavour briefly to explain.

Resting in unconformable stratification indifferently upon the Laurentian, the Montalban, or some intermediate terrane, is a series of rocks not less than 5000 feet in thickness (and in many parts greatly exceeding it), consisting in their lower part of quartzites and peculiar soft crystalline schists, and higher in the series including great beds of crystalline limestone, often magnesian, and becoming in many parts a banded or a white marble; the whole with more or less alternation of the soft schists, passing into argillites. This great series was, by the earlier investigators, Maclure, Eaton, and Emmons, supposed to be distinct from the Paleozoic rocks above the First or Transition Graywacke, and, with the exception of some intervening argillites, was included, under the names of Granular Quartz rock and Granular Lime rock, in the Primary or Eozoic, with the gneisses, mica-slates, &c. Above the Transition Graywacke, in the Champlain and Mohawk valleys, the researches of certain New York geologists soon after made known the existence of a series of quartzites and limestones directly overlaid by shales and sandstones, constituting the Second Graywacke, not unlike the First, with which these observers confounded it. These divisions, then and since designated Potsdam, Calciferous, Trenton, Utica, and Loraine, are highly fossiliferous, and very much less in aggregate thickness than the series elsewhere interposed between the older Primary and the First Graywacke. This series was, moreover, though not without certain traces of organic life, destitute of the fauna found in the fossiliferous strata above named, but contained many characteristic crystalline minerals. The metamorphic hypothesis was at that time—fifty years since—greatly in vogue, and led many geologists to imagine the Primary or Eozoic rocks to be wholly, or in great part, the result of a mysterious and unexplained alteration of Paleozoic strata, portions of which were supposed to be changed into the well-known adjacent gneisses and mica-schists. In like manner, it was assumed that the Granular Quartz rock and Granular Lime rock, with their interposed and immediately overlying schists, below the First Graywacke, were the metamorphosed representatives of the wholly distinct Potsdam-Trenton-Loraine divisions. These have an aggregate thickness of not more than 2000 feet, while the great and very unlike crystalline series, included by H. D. Rogers in Pennsylvania under the names of Primal Slate, Primal Quartzite, Auroral Limestone, and Matinal Shale, and having an aggregate thickness of not less than 5000 or 6000 feet, was declared to be their metamorphosed equivalent, extending throughout the great Appalachian valley.

This peculiar and distinct crystalline series constitutes what was subsequently called by Emmons Lower Taconic, and by the writer Taconian; the Upper Taconic of Emmons being the First Graywacke of the earlier writers. The Taconian rocks include mineral species which give to it a distinctive character as well as a great economic importance. Apart from the ores of zinc and of copper, must be mentioned, in the first place, those of iron. Of these, the hydrous ores, limonites, or brown hæmatites, found in the soft decayed strata, are of epigenic origin; that is to say, they result from the alteration *in situ,* through the action of water holding oxygen in solution, either of iron carbonate (siderite), or of iron pyrites, large deposits of both of which are met with in the upper part of the series, the carbonate, however, predominating. The percolation of atmospheric waters charged with oxygen converts by well-known reactions the iron carbonate into hydrous peroxide; any lime and magnesia present being removed as dissolved carbonate, while the iron is left as a hydrous peroxide, generally limonite. As I have elsewhere pointed out, the conversion of pure iron carbonate into limonite by this process involves a contraction of nearly twenty per cent., and as this change takes place from without inwards, and is generally accompanied by a rearrangement of the insoluble compound, it happens that the masses of limonite are cavernous and often concentric in structure. In some cases these hollow masses contain nuclei of carbonate, and large quantities of this unchanged mineral are met with in deep or in protected workings. The presence of manganese carbonate often gives an admixture of manganese oxides, which have been found in considerable quantities with these limonites in more than one locality.

Lenticular beds of iron carbonate which are but superficially changed to limonite are mined at Burden, Columbia Co., N.Y., where they appear a little east of the Hudson in gray white-weathering argillites with some calcareous and arenaceous beds, highly contorted, with eastern dips, and often overturned. They have lately been well described by Kimball, who, following the tradition of Mather, refers them to the Hudson-River group, which, as will be shown by a note farther on, was made by Mather to include alike Taconian, Cambrian, and Ordovician strata.

Less frequently in these strata are found beds of iron pyrites which, under favourable circumstances, have also suffered a process of oxidation resulting in the production of limonite. Several examples of this have been described in mines in Pennsylvania, where waters impregnated with iron sulphate appear, and unaltered pyrites is found in depth. Their structure will serve to distinguish the pyritous from the sideritic limonites, which latter are by far the more abundant in this series. While the accumulation alike of iron carbonate or iron sulphide has, in many cases, been effected by a process of segregation, all evidence in the epigenic processes here noticed points to the conversion of masses already *in situ*.

Crystalline magnetite and compact or scaly red hæmatite are alike frequently disseminated in the schists and quartzose layers of the lower part of this series, sometimes giving rise to lean siliceous iron ores, but at other times to deposits of great richness and economic value. To this horizon belong the mines of Cornwall, Boyerstown, Wheatland, Reading, and Dillsburg, appearing on the north side, and the Warwick and Jones mines on the south side, of the belt of Mesozoic sandstone in Pennsylvania.* Protected by this rock, and its accompanying dykes of dolerite, these remarkable deposits of magnetite have been by certain geologists regarded as of Mesozoic age; but, as I have long since shown, careful studies leave no doubt of the correctness of the later view of H. D. Rogers, who referred these ores to his so-called Primal Slate. The mineralogical characters of these ores are very distinct, and unlike those found in the old gneisses. Softer, more finely granular, and less coherent, they generally include small portions of iron sulphide, with a little manganese, cobalt, and copper; the latter sometimes in such proportions as to be separated with advantage in the process of mining. Considerable deposits of zinc ore (blende or calamine) are also met with in more than one locality in the limestones of this series.

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* See the author's *Mineral Physiology and Physiography*, pp. 261–268; also p. 538; also his further description of the Cornwall mine, *Trans. Amer. Inst. Mining Engineers*, iv. pp. 319–325; and Report E, Second Geological Survey of Pennsylvania.

These ore-bearing Taconian rocks are, however, by no means confined to the Appalachian valley. Even in their southward extension, while the chief belt is traced through eastern Tennessee and into Alabama (where the Taconian assumes a great thickness along the western base of the older crystalline rocks), several areas of it are found farther eastward on the Atlantic slope, which it probably once covered. One such subordinate belt is traced continuously from the main area in Pennsylvania into North Carolina, where it is one of four Taconian areas east of the Appalachian valley, which have there been alternately described as Huronian and Taconian. That of King's Mountain, which lies partly in North and partly in South Carolina, has a thickness of about 5000 feet, and is noticeable alike for its marbles, its quartzites, its limonites, and its magnetic and specular iron ores. It has been independently described by Oscar Lieber as an Itacolumitic group. Farther northward, also, Taconian areas occur in New England, along the Bay of Fundy, and in the Cobequid Hills in Nova Scotia, where they include important deposits of iron ores.*

The great iron-bearing horizon of northern Michigan, which extends into Minnesota and Wisconsin, is in crystalline schists, which were by Murray, and after him by Kimball and Credner, regarded as Huronian.† That they are distinct therefrom, and belong to an overlying series, including what was first distinguished by the writer in 1873 as the Animikie group, and that they coincide alike in mineralogical character and in stratigraphical position with the Taconian, had long been suspected. The independent researches of Rominger and of Irving leave, we think, no doubt that this iron-bearing series, provisionally referred to the Huronian, and including the writer's Animikie, is a great development in the north-west of the Taconian series. To this also the writer has referred smaller areas of similar iron-bearing rocks in Hastings county, Ontario, and in St. Lawrence county, New York. The conditions now presented around Lake Superior, where erosion has swept away the evidences of subaerial decay, while, however, sparing the harder magnetic and specular iron ores, and in many localities the epigenic limonites, which were there mined in the earlier times, are necessarily very unlike those of the Appalachian valley.

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* For a detailed account of this matter see in the author's *Mineral Physiology and Physiography*, "The Taconic Question in Geology," pp. 516–686; also *Ibid.*, 413–415, and "The Taconic Question Restated," *American Naturalist* for February, March, and April 1887. The Itacolumite group of Brazil, to which Lieber has with great probability compared the Taconian, is there one of much importance, alike stratigraphically and economically. It is, like the Taconian, auriferous and diamond-bearing, and its itabirite and specular schist represents the similar Taconian ores. The official reports of Lieber are very rare, but a pretty complete analysis of them, as regards this group, will be found in *Mineral Physiology*, &c., pp. 564–569. The Taconian limestone of King's Mountain has long been mined for gold. The series here rests upon Montalban gneisses and mica-schists, including granitic veins and masses which I find to be endogenous, carrying so much cassiterite as to have lately attracted considerable attention.

† The name of the Animikie group was in 1873 applied by the present writer to the slates and sandstones making the lower division of the upper copper-bearing series; the Huronian, upon which the Animikie was seen to rest unconformably, being the lower copper-bearing series of Logan. The sandstone and amygdaloids, which in their turn overlie unconformably the Animikie, were then also first claimed by the writer as a distinct series, named the Kewenaw or Keweenian. Irving's subsequent statement,

The space which we have thus given to the Taconian ore-deposits is more than justified by their great economic importance, not less than by the curiosities of their geological history. These ores from Lake Superior furnished in 1887 over 44 per cent., and with those from the Cornwall mine, and the brown hæmatites of the Appalachian valley, considerably over one-half of the total iron product of the United States.

The evidence drawn from the supposed contiguity of portions of fossiliferous rocks with the Taconian in certain localities within the great valley is discredited by not less clear evidence of the stratigraphical inferiority of the ore-bearing Taconian; while the absence of such ore-deposits in the same fossiliferous rocks throughout the regions in question may suffice to close the discussion.

The decay of crystalline rocks which has been noticed in connection with the limonite ores of the Taconian was a process universal in its application (as pointed out by the writer in 1870), and has been the source of all clays, sands, and boulders, the subsequent erosion and rearrangement of these by aqueous action being a very important factor in surface geology.* As we pro-

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that I regarded the Animikie as newer than the Kewenaw (Fifth An. Rep. U.S. Geol. Survey, 1885, p. 203), is totally at variance alike with the views and the language of the present writer. See *Mineral Physiology*, &c., pp. 414–415 and 578–583.

* See, for the whole question, an essay on "The Decay of Crystalline Rocks," *Mineral Physiology and Physiography*, pp. 246-278.

ceed southward through the United States we enter regions where portions of the decayed material still remain undisturbed, not only in the sheltered Appalachian valley, but on higher levels. Hence it is that we find great deposits of iron pyrites in Virginia, and farther southward, still enclosed in their walls of decayed gneiss and mica-schist, though already changed into limonite by oxidation. In many cases these superficial masses of oxide have attracted attention as iron ores, the working of which has not infrequently disclosed rearranged local accumulations of copper; while at depths of 100 feet or more an unchanged, and often more or less cupriferous, pyrites is met with in the unaltered gneiss. These deposits, though not of great or permanent value as iron ores, deserve mention the more as they often attract attention disproportionate to their importance. Space may here be found to describe a peculiar occurrence of limonite on Staten Island, New York. Here an area of several square miles has a surface of serpentine, which by decay *in situ* has been converted to a considerable depth into a brownish earthy matter, including concretionary masses and grains of a limonite, which, like the underlying serpentine, is chromiferous, and has in past times been the seat of a considerable mining industry; the whole presenting a very instructive example of the results of subaerial decay in an area which, probably from Mesozoic time, has been protected from erosion.

Having set forth the chief facts in the geological history of the iron ores of the great divisions of the crystalline rocks, it remains to notice those ores which are included in the deposits of Paleozoic time. Recognising in these the now generally accepted divisions into Cambrian, Ordovician, Silurian, Devonian, and Carboniferous (the latter including the generally recognised coal-measures, but excluding those of Mesozoic age), we note that the First or Transition Graywacke, the Upper Taconic, also designated Hudson-River and Quebec group,* while distinct from the Taconian proper, is limited to certain areas within the Appalachian valley, and with the exception of occasional portions of overlying and included Ordovician and Silurian, is Cambrian in age. It is uncrystalline in character, and is not known to contain any workable deposits of iron ores whatever. The same may be affirmed of the succeeding Ordovician, including the Trenton limestone and its overlying Utica and Loraine shales. The notion of the supposed identity of this group with the Taconian has already been discussed and rejected in these pages. This Ordovician group passes upward into the true Silurian, consisting in its lower portion of the sandstones which are known in the State of New York as Oneida and Medina, and in conjunction with the underlying Ordovician shales make up what has been called the Second Graywacke; the confounding of which with the First Graywacke has been the cause of many errors in American geology.*

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* See, for a concise statement, "The Geological History of the Quebec Group," *American Geologist* for April 1890; also the preface to the second edition of *Mineral Physiology*, &c.

Resting upon the sandstone just named, and between it and the great overlying Niagara limestone of the Silurian, is a subordinate limestone division locally known as the Clinton, which is of interest as including the first iron ore of our Paleozoic series. This is a stratum a few feet in thickness in a marine fossiliferous limestone, the organic remains in which are cemented together by red oxide of iron or hæmatite. This ore-horizon, variously designated as the Clinton, the dyestone, and the fossil ore, is traced from the vicinity in the great lakes of the north, eastward beneath and around the Appalachian coal-basin as far as Alabama, and is mined and smelted in many localities. As a fact of geological interest, it may be mentioned that the great movements of the strata which in Alabama have subdivided the coal-measures and brought to the surface between the Warrior and the Cahaba coalfields the brown hæmatites of the Primal or Taconian, as elsewhere in the great valley, with their enclosing clays, have exposed considerable outcrops of the Clinton ore, which it thus brought into close proximity at once with these higher-grade ores and with the valuable coking coals of the region. The Clinton or dyestone ore is, however, of inferior quality; and in the deeper workings, where solution has not removed the included calcareous fossils, is often no longer rich in iron. A somewhat similar ore-horizon occurs with the Oriskany sandstone at the base of the Devonian. It is often very siliceous, but is mined in parts of Virginia, where it yields a valuable iron ore.

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* It was W. W. Mather who, fifty years since, by his denial of the existence of the First Graywacke of Eaton, and his attempt to show that this ancient uncrystalline group, together with the whole underlying Taconian, the Trenton limestone, and the Second Graywacke itself, were modifications of the Potsdam-Trenton-Loraine series, or the so-called Champlain division of New York Paleozoic rocks, in various stages of alteration, caused this confusion. From him, and from Vanuxem, came the use of the term Hudson-River group (afterwards changed by Logan to Quebec group) for these schistose rocks of three distinct periods, which were all assumed to be equivalent to the Loraine shales.

Passing upward into the coal-measures of the Appalachian basin, we meet, at various horizons, iron ores which may be described, mineralogically, as belonging to two distinct classes. Of these, the most abundant are those consisting essentially of carbonate of iron, either as so-called blackband ore or as massive or concretionary clay ironstone, which, near its outcrop, is transformed by peroxidation into limonite, with the loss of any combined lime or magnesia and the hydration of the iron oxide. The second type is the anhydrous peroxide or red hæmatite, which, though more rare, is found in many localities in concretionary masses of such great hardness and compactness as to have attracted the notice of the aborigines, who fashioned them into arrow-heads and other weapons.

The concentration of iron carbonate in rocks by the intervention of organic matter reducing and rendering soluble the ferric oxide diffused through the sediments has been studied by many chemists, notably by W. B. Rogers; while Shaler has called attention to the conversion of layers of carbonate of lime in the coal-measures by percolation from above, a replacement explained by the chemical reactions observed between carbonate of lime and dissolved bicarbonate of iron. The subsequent conversion of such iron carbonates into limonite is familiar, but the generation instead of this of a half-hydrated species, as turgite, or an anhydrous form, as in the compact red hæmatite found in these Paleozoic strata, is not well understood. The interstratified ores of the coal-measures form a not inconsiderable source of iron in various parts of the great Appalachian coalfields; while similar ores abound, and were at one time smelted to some extent, in the western coalfield in Kentucky.

It may be said, in general terms, that the abundant supplies of richer and easily mined ores in localities not too remote from the coal have greatly contributed to their development. It remains to be noted that, with the exception of the deposits in the

Atlantic belt in New York and New Jersey, the ores of the United States are not favourably situated for the production of iron for foreign markets. This consideration has given an importance to the trade in foreign iron ores which, notwithstanding a considerable duty imposed, has in the last few years assumed considerable proportions. High-grade ores from Spain, Algiers, Italy, Greece, from Cuba, and to a limited extent from Canada, must be reckoned as factors in our iron industry.*

The Atlantic belt in New England, and in the province of Quebec, has afforded little iron ore, though there are undeveloped possibilities in several localities; while there is reason to believe that in the maritime provinces of Nova Scotia and New Brunswick, alike in the Paleozoic basin, with its included coal-measures, and in the older crystalline rocks, there are iron-deposits which, from their proximity to coal, and from their accessibility by sea, may one day assume considerable economic importance.

In bringing to a close this review of the iron ores of the country, necessarily very meagre and incomplete, no apology is attempted for the manner in which it has been presented, and this for the reason that I believe the end which I have had in view will be best subserved by the geological method here adopted. The geographical distribution of the various ores, their relation to the supplies of coal, and of the centres of production and manufacture alike to home and foreign markets, are obvious to the general student, without any special reference to the geological distribution of the ores. The consideration of these, and of the subordination of the special types of ores to certain geological horizons, are, however, less familiar to our ironmasters, and at the same time will always possess a great significance.

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* The following figures will suffice to give a notion of the absolute and relative importance of the importations of iron ore to the United States for the fiscal years ending June 30, 1887, and June 30, 1888, which amounted respectively to 1,441,774 tons and 917,644 tons of ores carrying from 50 to 60 per cent. of iron:—

	1887.	1888.
Spain	45·8	45·0
Algeria	18·8	1·77
Italy	10·0	10·7
Greece	4·0	3·7
England	6·3	6·2
Cuba	9·6	16·0
British North America	2·1	1·5

The imports from Cuba for 1888-89 had risen to 34·5 per cent. of 652,032 tons.

Such a study as the present must necessarily be supplemented by an elaborate chemical investigation of these different classes of ores, considered alike in their relations to blast-furnace practice and to their respective adaptability to the various branches of iron and steel industry. I need not remind you of the great amount of information already acquired by the skill of the manufacturers and the scientific knowledge of our metallurgical chemists. Another hand more trained than my own is needed to attempt the task of discussing it.

APPENDIX.

A.—*VISITS AND EXCURSIONS IN THE UNITED STATES.*

THE Council of the Iron and Steel Institute having decided that a special memorial volume shall be prepared and issued, giving an account of the numerous visits and excursions made by the members of the Institute during their stay in the United States, and containing special papers in relation thereto, it is proposed here to give a bare outline only of the lengthy and interesting programme that was presented for their acceptance.

The afternoon of Wednesday, October 1st, the first day of the meeting in New York, was devoted to an excursion on the Hudson River. The steamship *Sandy Hook* was offered by the Local Reception Committee for this purpose, and favoured with fine weather, a very enjoyable afternoon was spent, lunch being provided on the boat by the New York Reception Committee.

On Thursday, October 2nd, a party of members visited the works of the Consolidated Gas Company, under the guidance of Mr. J. B. Mackintosh, in the morning; while the afternoon was spent, partly in examining different works and objects of interest in New York, partly in assisting at the unveiling of the statue raised by the American Engineers to perpetuate the memory of the late Alexander L. Holley (*vide* p. 369, *ante*).

In the evening, the Annual Dinner of the Institute took place at Delmonico's Restaurant, when about 270 sat down. A reception was given the same night to the members of the Verein Deutscher Eisenhüttenleute at the Liederkranz, West Fifty-ninth Street.

On the morning of Friday, October 3rd, a party of members, under the guidance of Mr. S. S. Wheeler, visited the electrical works of New York City.

In the afternoon there were three local excursions:—The first, by the steamship *Laura M. Starin*, on the East River, to the Navy Yard, the De la Vergue refrigerating works, and the Washington Bridge, Harlem River; the second, by special train, to the Tilly Foster ore mines and electrical separating works; and the third, by special train, to the Edison Laboratory at Llewellyn Park, where Mr. Edison kindly received and entertained his guests.

On Saturday morning, October 4th, the members of the Institute left New York by special train for Philadelphia. Here they were received by the Philadelphia Local Committee, and after an excursion on the Delaware River, during which they were entertained at luncheon, they were conveyed to their respective hotels in the city. Monday was devoted to visits to the large manufacturing establishments of Philadelphia, including the Baldwin Locomotive Works, the works of Messrs. Sellers, and others.

On Monday evening, October 6th, the members were entertained at a reception at the Academy of Fine Arts.

On Tuesday, October 7th, the members left Philadelphia in special trains for Cornwall, visiting the great ore banks of that name, and the Colebrook blast furnaces near thereto, owned by the same proprietary. During the night the party were conveyed to Altoona.

On Wednesday, October 8th, the party was shown over the extensive locomotive, general engineering, and carriage-building works at Altoona, belonging to the Pennsylvania Railroad Company, the conductors being Mr. Theo. N. Ely, the locomotive superintendent, and Dr. C. B. Dudley, chemist to the Company. The afternoon was devoted to a trip up and down the Conemaugh Valley, from East Conemaugh, through the Gautier and Cambria works of the Cambria Iron Company at Johnstown. The Haws silica and firebrick works and the plant of the Johnson Company were also visited.

From the 9th to the 12th of October the members were at Pittsburgh, whither they were conveyed by special train. The Pittsburgh Committee had prepared a very full programme of visits, which in cluded the works of Carnegie Brothers, and Carnegie, Phipps, & Co. (Edgar-Thomson and Homestead), to which an afternoon was devoted (the party travelling by special steamer on the Monongahela River), the Connellsville coke region, through which the party was conducted by Mr. Andrew Carnegie, Mr. H. C. Frick, and others; and numerous works in the city and neighbourhood.

On Saturday evening, October 11th, the members and their lady friends were entertained at a reception at Carnegie Hall, Allegheny City.

Monday, October 13th, and Tuesday, October 14th, were spent at Chicago, which was reached on the morning of the former day. On Monday forenoon the members were received at the Palmer House Hotel by the Mayor of Chicago, who was accompanied by the principal Aldermen and Corporation officials, and by whom the freedom of the city was tendered to the President of the Institute in a suitable illuminated address, drawn on vellum. The afternoon was devoted to seeing the city and its suburbs. In the evening the members were entertained at a reception in the Auditorium Building.*

On Tuesday, the 14th of October, a special train conveyed the members and others to the large works of the Illinois Steel Company at South Chicago, and to the Pullman car works of Pullman, near Chicago. Fowler's pressed steel works were examined *en route.*

On Tuesday evening the party broke up into two sections, the larger section proceeding direct to Birmingham, Alabama; thence to Shelby and Anniston, Chattanooga (where Sunday, October 19th, was spent on Lookout Mountain), Middlesbrough (Kentucky), Pulaski, Cripple Creek, Pocahontas, and Roanoke (Virginia); and finally, on the 25th of October, reaching Washington.

The other section, proceeding northwards, visited, in turn, the compressor plant of the Chapin Mining Company at Quinnessec Falls, and the mining plant of the Chapin Mining Company at Iron Mountain (Michigan), the iron mines of the Gogebic Range, the Lake Superior copper region at Houghton (where they were entertained by the copper companies at lunch, and by the citizens of Houghton at an evening reception), visiting the Calumet and Hecla stamp mills, smelting works and mines; the Quincy, Franklin, and

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* A description of this vast structure is to be found in *Engineering* of Saturday, April 4th, 1891.

Atlantic mines and mills; the Tamarack mine, stamp mills, smelting works, and copper rolling mill; and the Michigan School of Mines, the leading iron mines of the Marquette range, the canal and locks at Sault St. Marie, and the nickel mines of Sudbury, Ontario.

After reassembling at Washington (where they were received at the White House by the President of the United States), the two parties were conveyed by special train to Sparrow's Point, near Baltimore, where they visited the new plant of the Pennsylvania Steel Company; and thence, after a run up Chesapeake Bay to Baltimore Harbour, proceeded to Niagara Falls and New York.

A considerable number of members, instead of proceeding direct from Niagara Falls to New York, accepted an invitation from the Thomson-Houston Electric Lighting Company and the Thomson Electric Welding Company to visit their extensive works at Lynn, near Boston.

Another party of nearly a hundred accepted the invitation tendered at the New York meeting, on behalf of the Canadian Government, to visit the Dominion, and this trip embraced the cities of Hamilton, Toronto, Ottawa, and Montreal, as well as a run to the nickel mines of Sudbury, the excursion extending over about a week.

Special trains of Pullman cars were placed at the disposal of the visitors, both in the United States and in Canada, and the utmost hospitality was shown on all hands.

APPENDIX B.—TABLE *showing the Effects of the use of a Metal Mixer on the Pig Iron made at the Edgar-Thomson Steel Works, Pittsburgh.*

The following tabular statement, showing the effects of the adoption of the metal mixer employed at the Edgar-Thomson Steel Works, Pittsburgh, on the uniformity of the pig iron used in the converters, has been kindly supplied by Mr. Gayley, through Mr. P. C. Gilchrist.

Analysis of Iron from Ladles filled consecutively at Furnaces.
June 1890. Weight of Ladles, 10 gross tons.

Sampled at Furnace.				Sampled at Steel Works after Passing Through Metal Mixer.		
Furnace.	No. of Ladle.	Silicon.	Sulphur.	No. of Ladle.	Silicon.	Sulphur.
		Per Cent.	Per Cent.		Per Cent.	Per Cent.
3	1	·675	·034	1	1·002	·017
,,	2	·675	·016	2	1·001	·014
,,	3	1·049	·034	3	1·194	·013
,,	4	·970	·021	4	·684	·012
,,	5	1·305	·013	5	1·502	·012
,,	6	1·385	·010	6	·935	·012
,,	7	·908	·028	7	·935	·013
,,	8	1·119	·023	8	·792	·012
,,	9	·933	·014	9	·829	·013
2*	10	2·402	trace	10	·699	·005
4	11	·675	·007	11	·956	·009
,,	12	·722	·007	12	·886	·012
,,	13	·746	·014	13	1·040	·020
,,	14	·624	trace	14	·909	·021
,,	15	·684	·005	15	1·096	·014
,,	16	·736	·007	16	·862	·021
,,	17	·561	·014	17	·956	·018
3	18	1·063	·006	18	·909	·020
,,	19	1·223	·006	19	2·099	trace
,,	20	1·455	·007	20	1·493	·005
,,	21	1·563	·006	21	1·376	·010
,,	22	1·296	·007	22	2·103	002
3	23	1·186	·006	23	1·446	·012
,,	24	1·446	·006	24	1·400	·012

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* This was a special heat to start the turn with.

Sampled at Furnace.				Sampled at Steel Works after Passing Through Metal Mixer.		
Furnace.	No. of Ladle.	Silicon.	Sulphur.	No. of Ladle.	Silicon.	Sulphur.
		Per Cent.	Per Cent.		Per Cent.	Per Cent
2	25	1·857	·006	25	1·348	·012
,,	26	2·075	·005	26	1·329	·010
,,	27	1·973	·002	27	1·400	·007
,,	28	2·613	·003	28	1·376	·013
,,	29	2·215	none	29	1·180	·013
3	30	1·329	·032	30	1·540	·010
,,	31	1·282	·026	31	·933	·020
,,	32	1·329	·019	32	1·166	·017
,,	33	1·320	·019	33	·933	·020
,,	34	1·320	·014	34	1·026	·017
,,	35	1·306	·017	35	·923	·032
,,	36	1·306	·012	36	·979	·027
,,	37	1·446	·012	37	·862	·032
4	38	·606	·049	38	·933	·028
,,	39	·792	·049	39	·792	·027
,,	40	·979	·048	40	·909	·026
,,	41	·792	·052	41	·956	·026
,,	42	·699	·033	42	1·002	·033
,,	43	·746	·043	43	1·180	·021
,,	44	·675	·046	44	·956	·027
,,	45	·699	·054	45	1·142	·024
,,	46	·652	·033	46	1·180	·025
3	47	·965	·030	47	1·282	·029
,,	48	·956	·020	48	1·516	·028
,,	49	1·189	trace	49	1·244	·024
,,	50	·933	,,	50	1·493	·018
,,	51	1·073	,,	51	1·376	·024
,,	52	1·213	·018	52	1·493	·018
,,	53	1·007	·018	53	1·166	·016
,,	54	1·119	·010	54	1·400	trace
2	55	2·052	trace	55	1·563	·016
,,	56	1·935	,,	56	1·540	·015
,,	57	2·239	·007	57	1·493	·007
,,	58	2·075	·020	58	...	·012
,,	59	2·131	·020	59	...	·027
,,	60	1·726	·009	60	...	·023
5	61	1·119	·026	61	1·306	·037
,,	62	1·189	·005	62	·976	·013
,,	63	1·259	·004	63	·839	trace
,,	64	1·610	·005	64	·862	·037
,,	65	1·960	·007	65	·918	...
,,	66	1·927	·007	66	·839	...
,,	67	1·446	·005	67	1·189	...
4	68	·364	·085	68	·886	·032
,,	69	·624	·095	69	1·260	·038
,,	70	·606	·099	70	1·189	·033

Furnace.	Sampled at Furnace.			Sampled at Steel Works after Passing Through Metal Mixer.		
	No. of Ladle.	Silicon.	Sulphur.	No. of Ladle.	Silicon.	Sulphur.
		Per Cent.	Per Cent.		Per Cent.	Per Cent.
4	71	·476	·087	71	·956	·042
„	72	·998	·079	72	1·703	·032
„	73	·839	·080	73	·956	·027
„	74	1·017	·090	74	1·213	·025
„	75	1·563	·039	75	·956	·030
„	76	2·324	trace	76	1·260	·023
„	77	1·586	·026	77	1·890	·002
„	78	1·554	·019	78	1·073	·018
3	79	·910	·036	79	1·049	·017
„	80	·639	·029	80	1·143	·013
„	81	·793	·021	81	1·087	·007
„	82	·830	trace	82	·970	·006
„	83	·830	·023	83	1·152	trace
„	84	1·082	·015	84	1·189	...
„	85	1·117	trace	85	1·381	·029
5	86	1·003	trace	86	1·241	trace
„	87	1·213	„	87	1·208	·038
„	88	1·166	„	88	1·049	·029
„	89	·910	„	89	1·035	·027
„	90	1·129	„	90	1·003	·032
„	91	1·082	„	91	1·203	·025
2	92	1·166	...	92	1·227	·027
„	93	1·470	·072	93	1·189	·034
„	94	1·913	·093	94	1·129	·036
„	95	1·932	·055	95	1·343	·032
„	96	1·109	·079	96	1·390	·020
2	97	1·185	·059	97	1·227	·015
1	98	1·727	·034	98	1·418	·013
„	99	1·540	·042	99	1·446	·009
„	100	1·866	·032	100	1·502	·010
„	101	1·171	·056	101	1·189	trace
3	102	1·960	trace	102	1·484	·009
„	103	1·070	·008	103	2·030	·011
„	104	1·152	·004	104	1·329	·025
„	105	1·516	·014	105	1·334	·036
„	106	1·680	trace	106	1·096	·011
„	107	1·343	·017	107	1·329	·042
„	108	1·353	trace	108	1·292	·046
...	...	...	...	109	1·236	·048
Average	...	1·336	·023	...	1·186	·019

STRATE MR. GAYLEY'S PAPER ON “THE DEVELOPMENT OF AMERICAN BLAST FURNACES.”

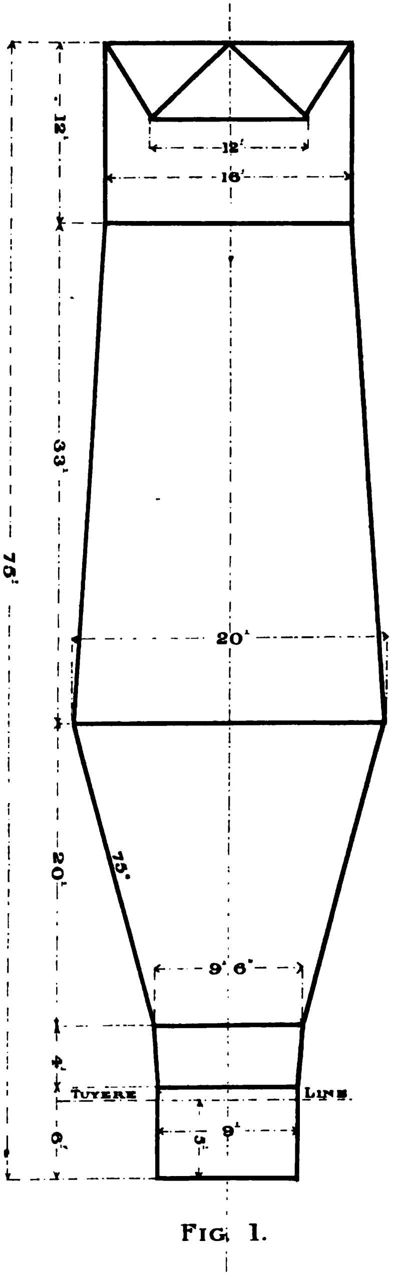

FIG. 1.

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PLATE II.

TO ILLUSTRATE MR. GAYLEY'S PAPER ON "THE DEVELOPMENT OF AMERICAN BLAST FURNACES."

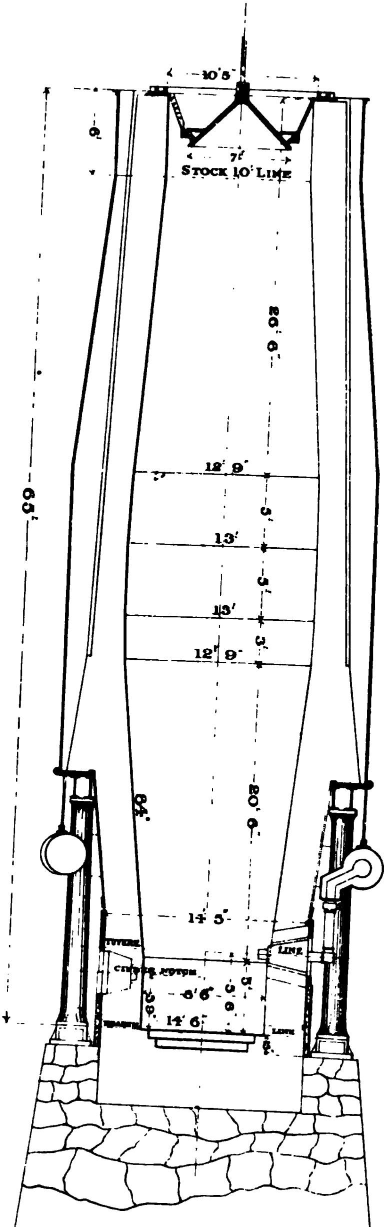

FIG. 2

Journal of the Iron & Steel Institute

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PLATE III.

TO ILLUSTRATE MR. GAYLEY'S PAPER ON "THE DEVELOPMENT OF AMERICAN BLAST FURNACES."

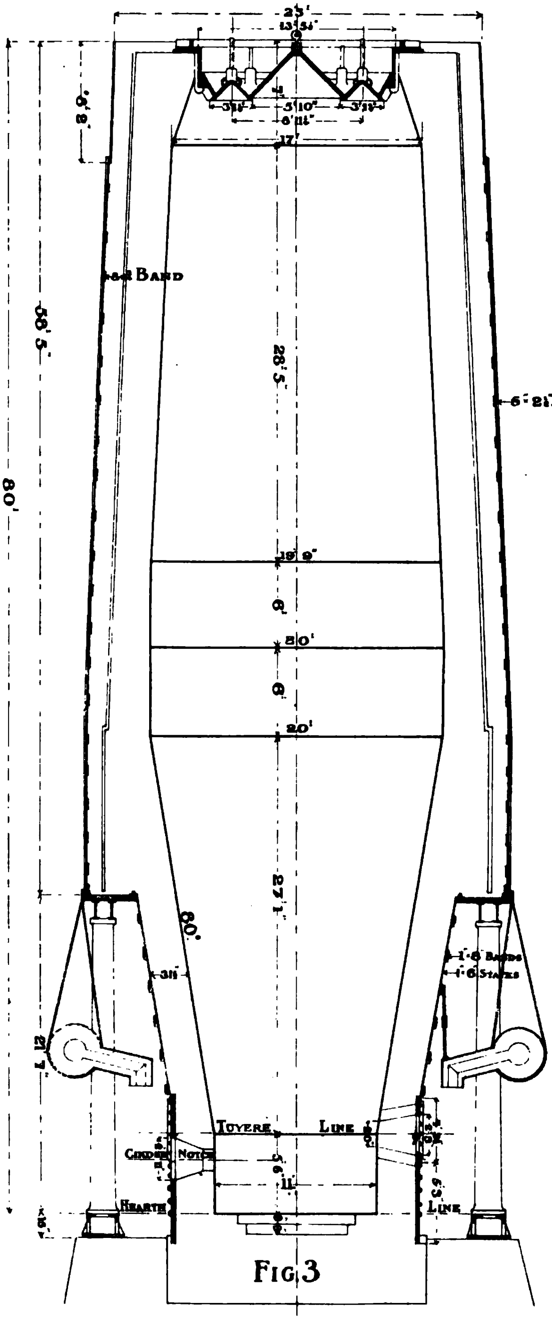

FIG 3

Journal of the Iron & Steel Institute

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TO ILLUSTRATE MR. KENT'S REMARKS ON MR. GAYLEY'S PAPER.

DIAGRAM, SHOWING THE CONDITIONS AND RESULTS OF PIG-IRON PRODUCTION AT THE ISABELLA AND LUCY FURNACES, PITTSBURGH, PA. PLOTTED IN PART FROM MR. JAMES GAYLEY'S "ABSTRACT OF RESULTS."

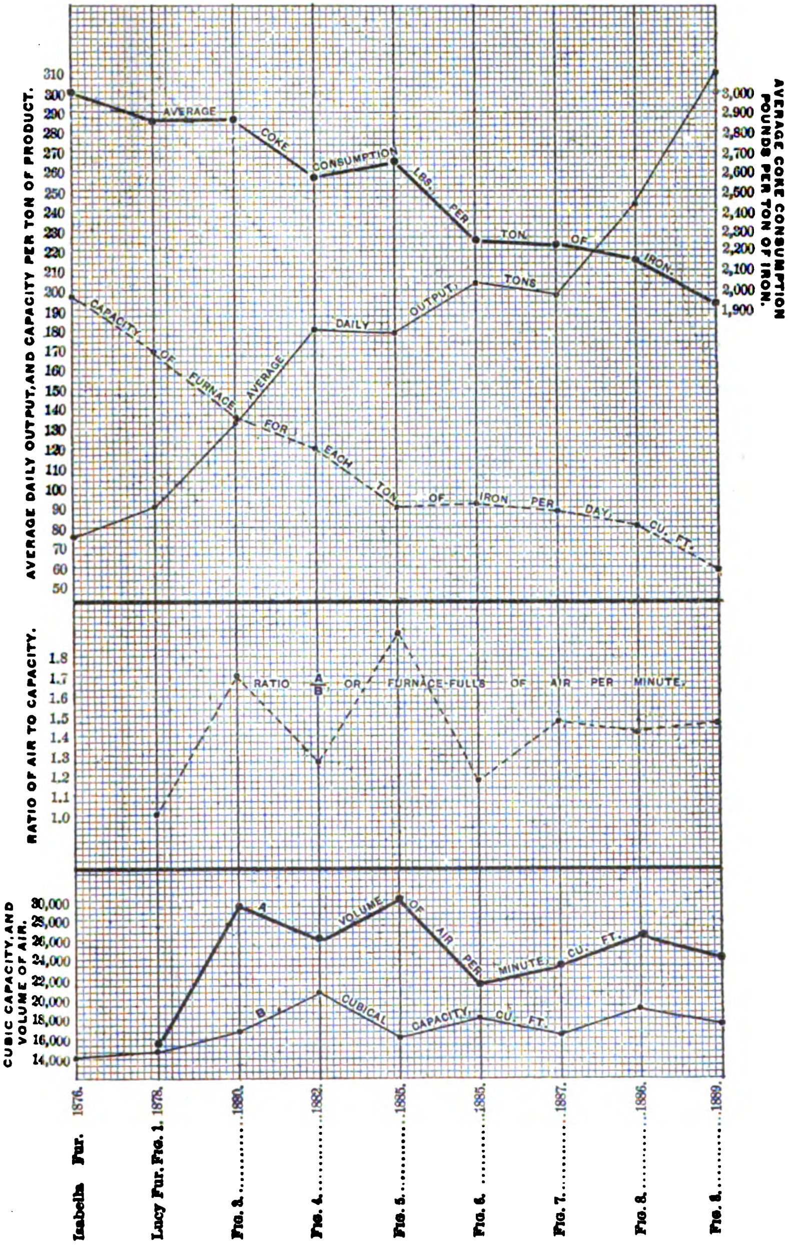

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PLATE IX.A

MANUFACTURE

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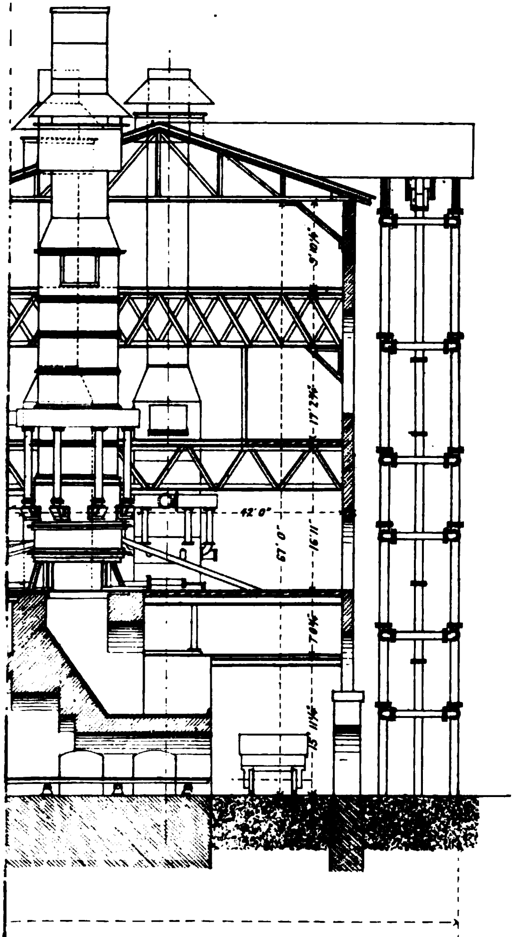

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Ballantyne, Hanson & Co. Edinburgh & London.

TO ILLUSTRATE MR. H. M. HOWE'S PAPER ON "THE MANUFACTURE OF STEEL IN THE UNITED STATES."

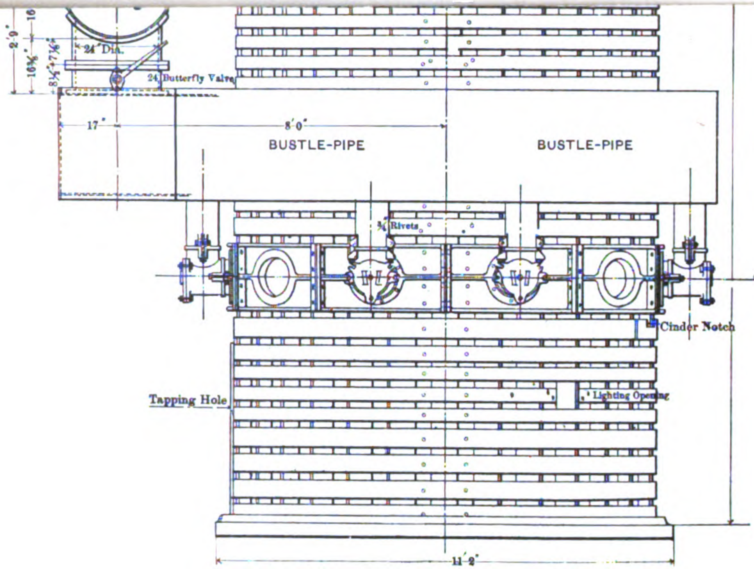

FIG. 3.

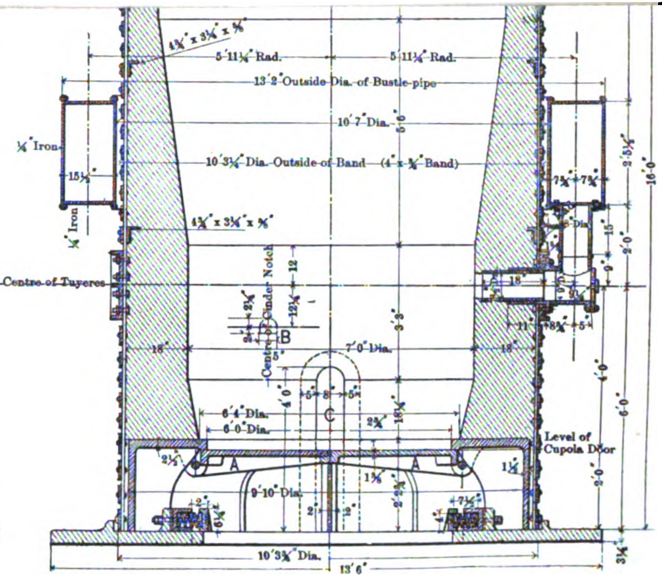

FIG. 4.

Ballantyne, Hanson & Co. Edinburgh & London.

E MANUFACTURE

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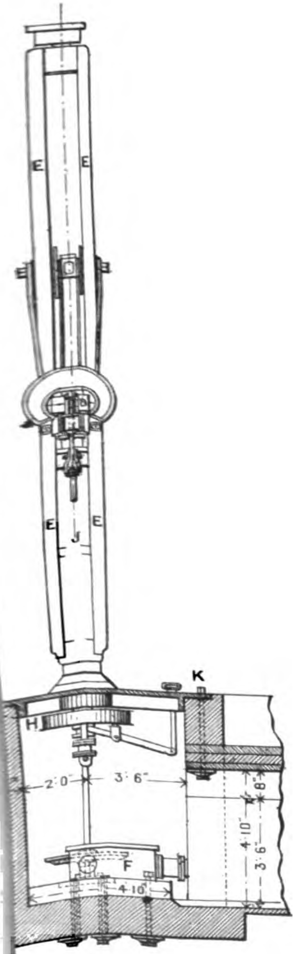
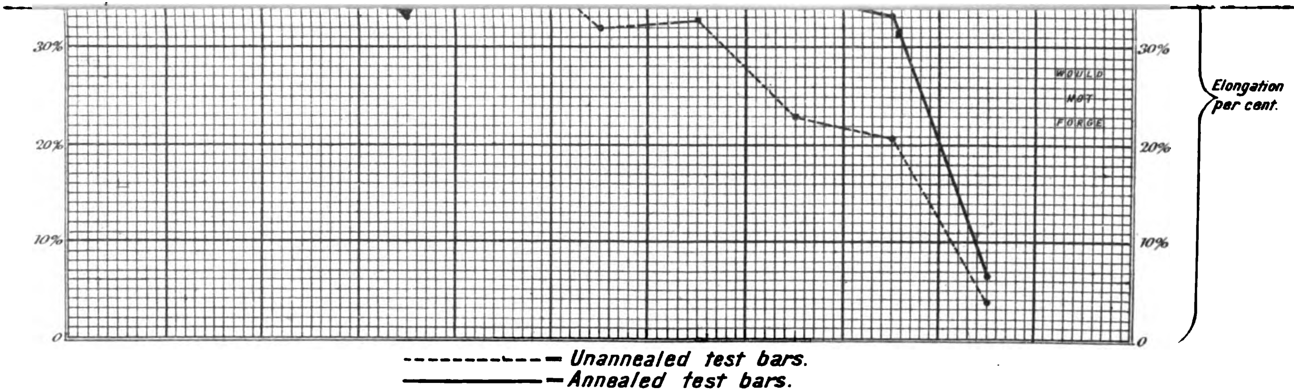


Ballantyne, Hanson & Co. Edinburgh & London.

PLATE XII.



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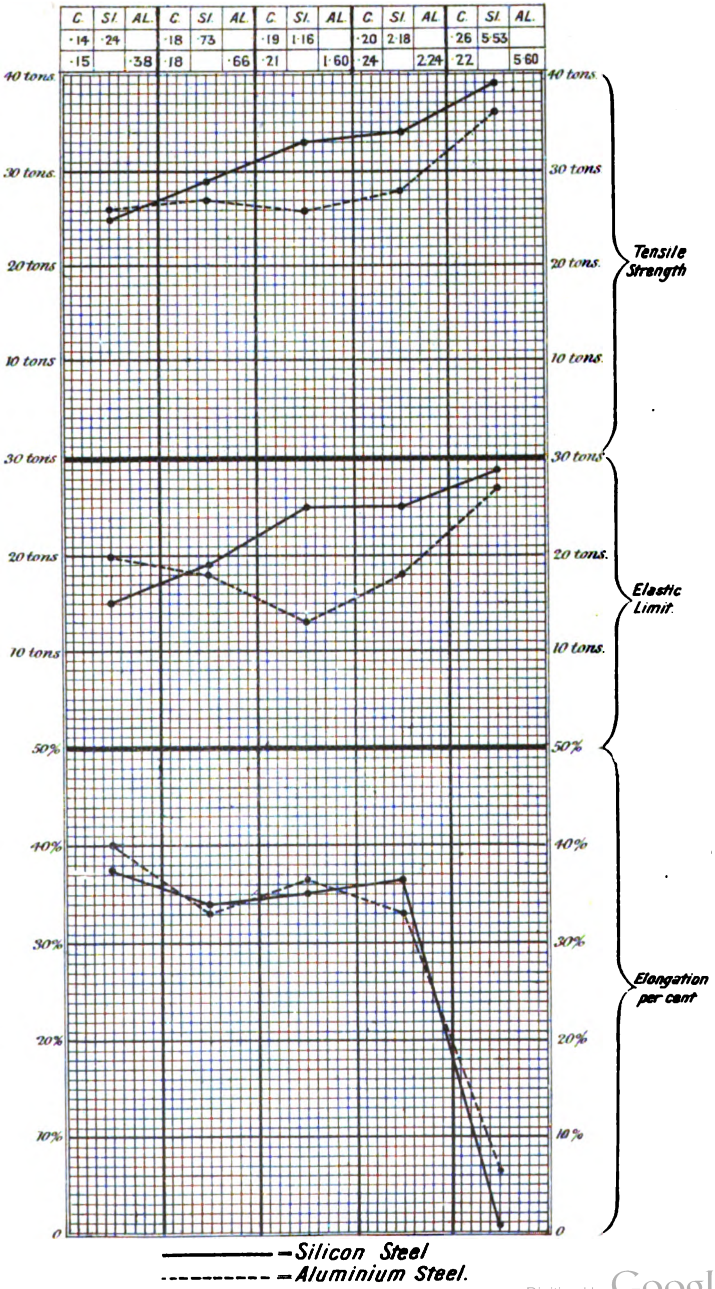
TO ILLUSTRATE MR. HADFIELD'S PAPER ON ALUMINIUM STEEL.

Diagram II. *Shewing comparison between forged Silicon and Aluminium Steel: Plotted from Table II; both materials having been annealed.*



C.	SI.	AL.	C.	SI.	AL.	C.	SI.	AL.	C.	SI.	AL.	C.	SI.	AL.
·14	·24		·18	·73		·19	1·16		·20	2·18		·26	5·53	
·15		·38	·18		·66	·21		1·60	·24		2·24	·22		5·60

MINIUM STEEL.

TEEL

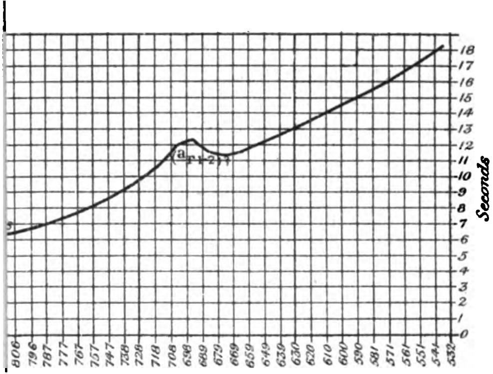
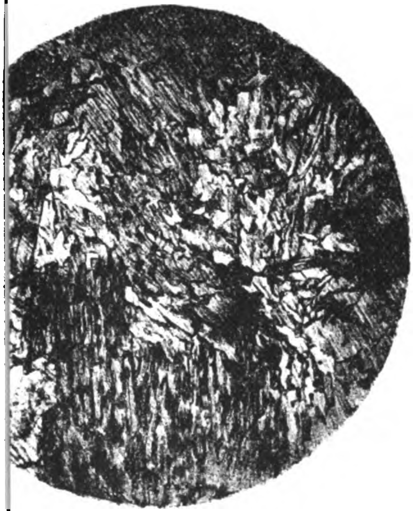


Fig. 3.

D STEEL AFTER ANNEALING AT 1390°C
MAGNIFIED 45 LINEAR
(by M. Osmond)



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TO ILLUSTRATE MR. HADFIELD'S PAPER ON ALUMINIUM STEEL.

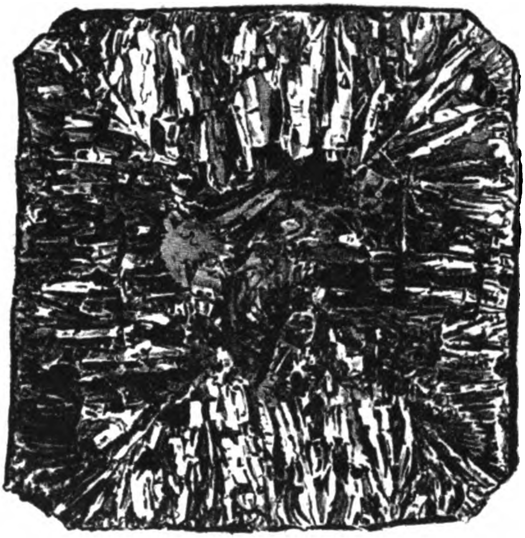

Fig 4.
ACTUAL SIZE OF CAST 5% SILICON STEEL.

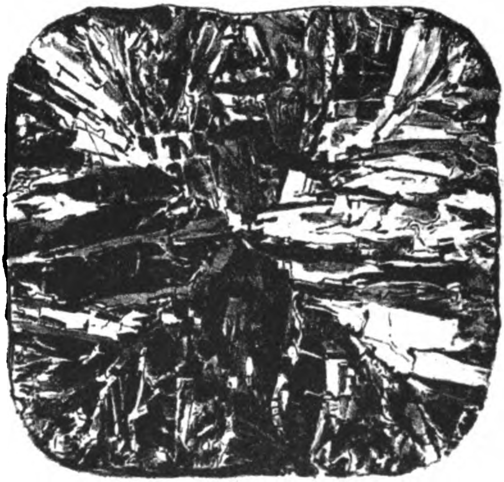

Fig. 5.
ACTUAL SIZE OF CAST 5% ALUMINIUM STEEL.

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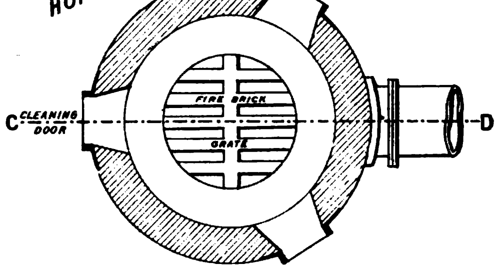
TO ILLUSTRATE MR. BURDETT LOOMIS'S PAPER ON FUEL GAS.

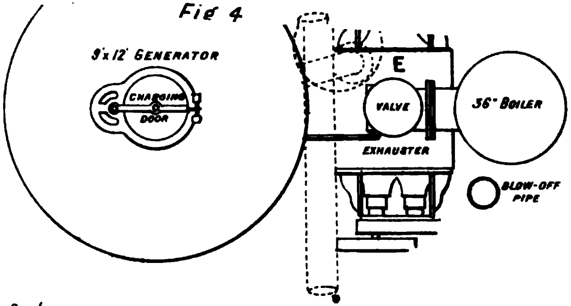
HORIZONT[illegible] ON LINE A B

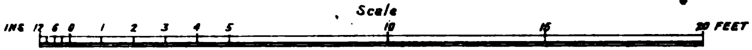
Fig. 3



PLAN

Fig 4

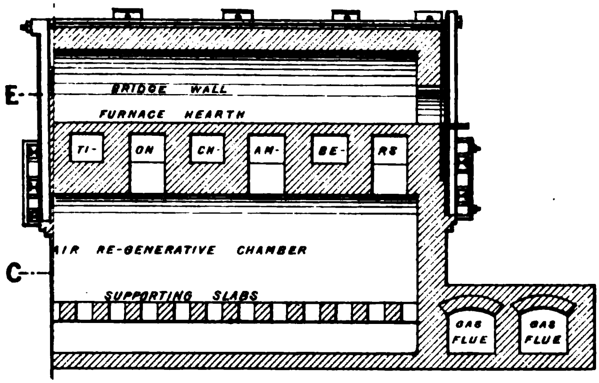




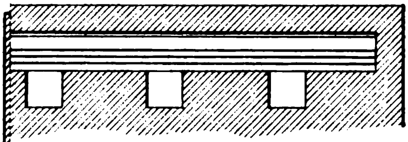
Ballantyne, Hanson & Co Edinburgh & London.

PLATE XVII.

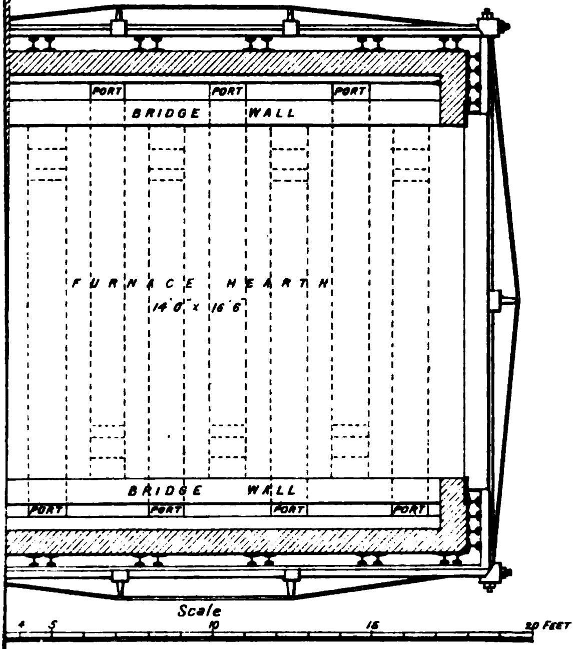
CAL SECTION ON LINE A B



CAL SECTION ON LINE J K



IZONTAL SECTION ON LINE E F



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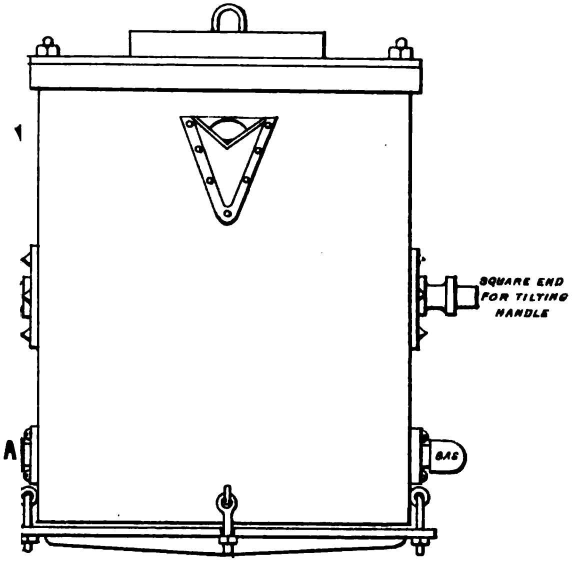
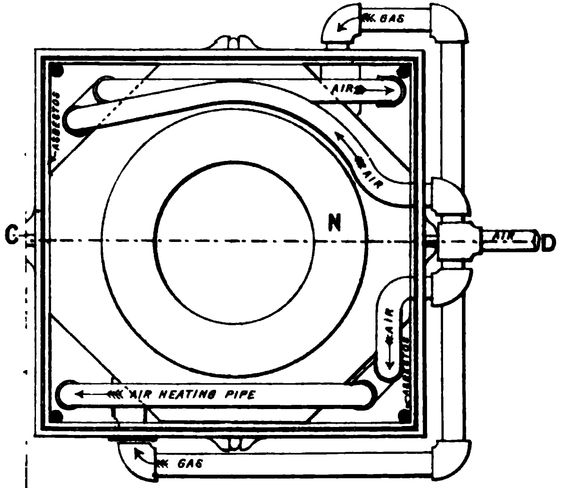
FRONT ELEVATION.



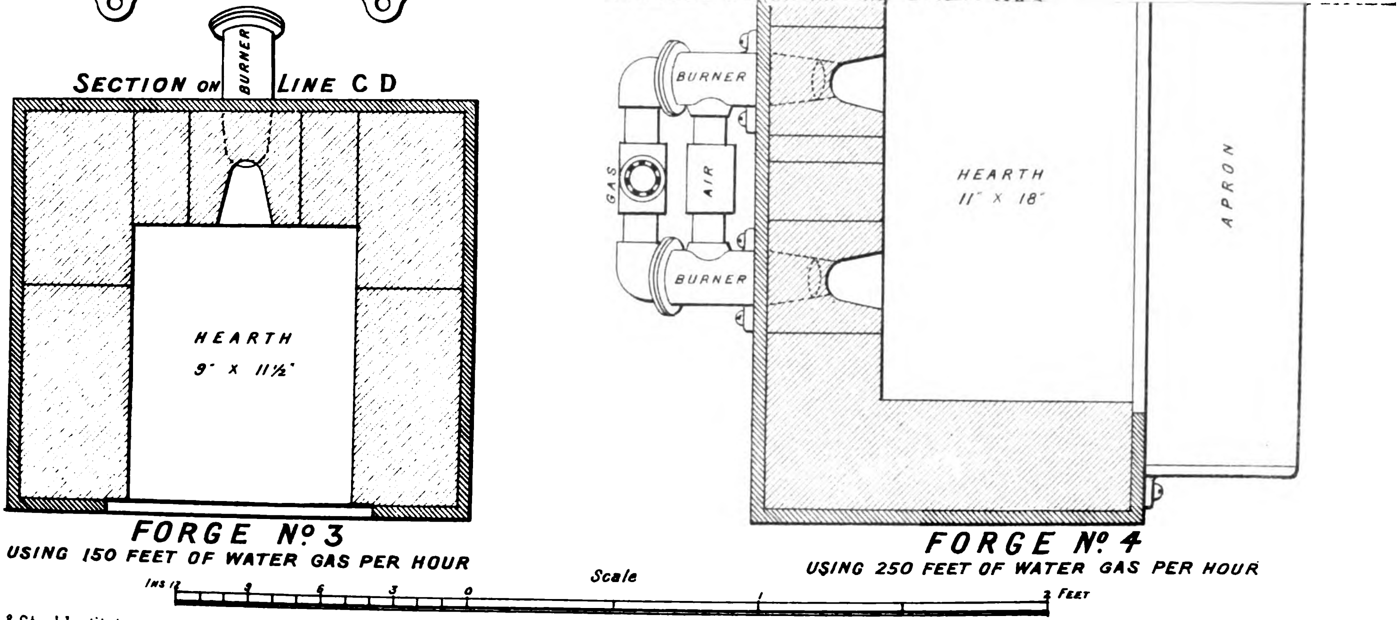
TOP VIEW OF PIECE N.
AND SHOWING AIR HEATING PIPES.



Ballantyne, Hanson & Co. Edinburgh & London.

PLATE XIX.

TO ILLUSTRATE MR. BURDETT LOOMIS'S PAPER ON FUEL GAS



FORGE No. 3
USING 150 FEET OF WATER GAS PER HOUR

FORGE No. 4
USING 250 FEET OF WATER GAS PER HOUR

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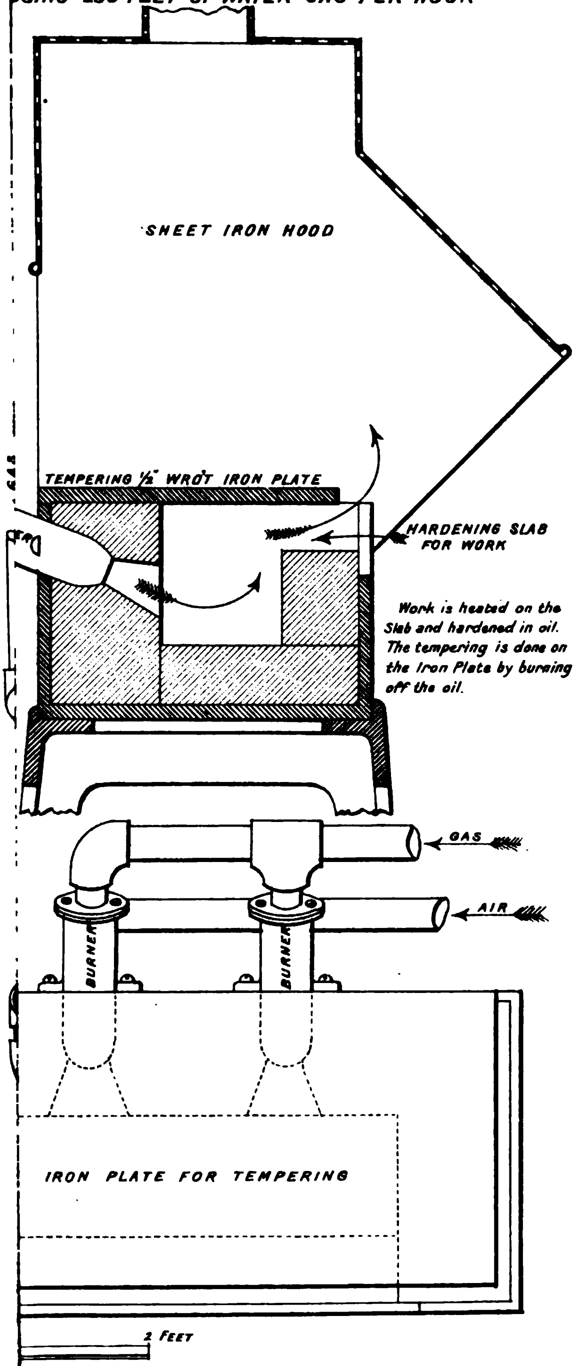
CROSS SECTION
USING 250 FEET OF WATER GAS PER HOUR



Work is heated on the Slab and hardened in oil. The tempering is done on the Iron Plate by burning off the oil.

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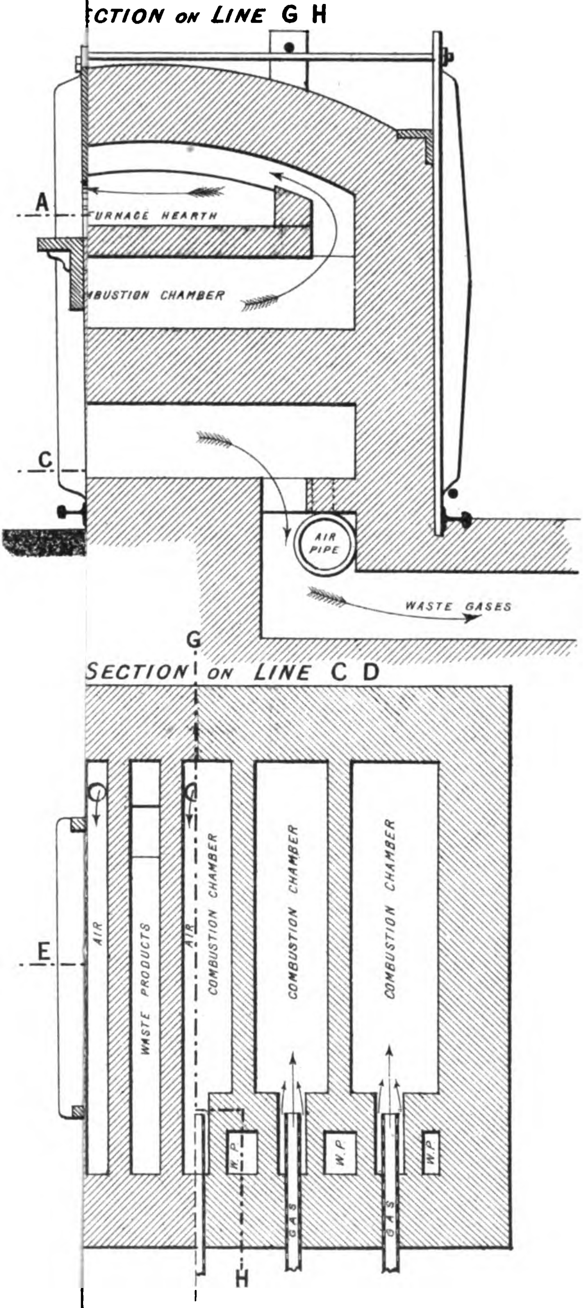
AS. PLATE XXI.

GAS.



CTION ON LINE G H

SECTION ON LINE C D

FEET

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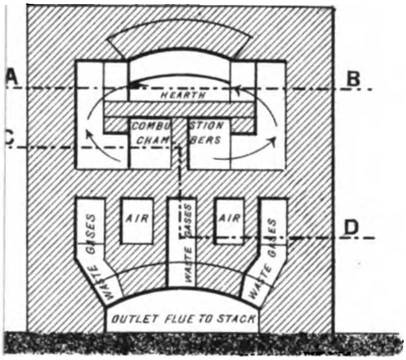
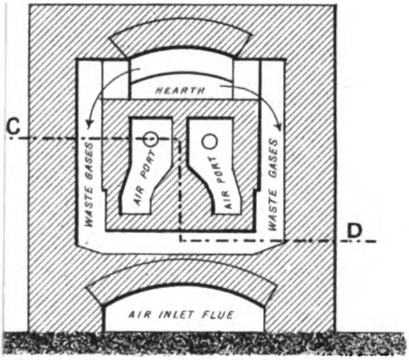
PLATE XXII.

FUEL GAS.



CROSS SECTION ON LINE E F



CROSS SECTION ON LINE G H

BLAST ROD FURNACE

ED WITH WATER GAS

TION 500 FEET PER HOUR

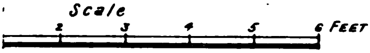


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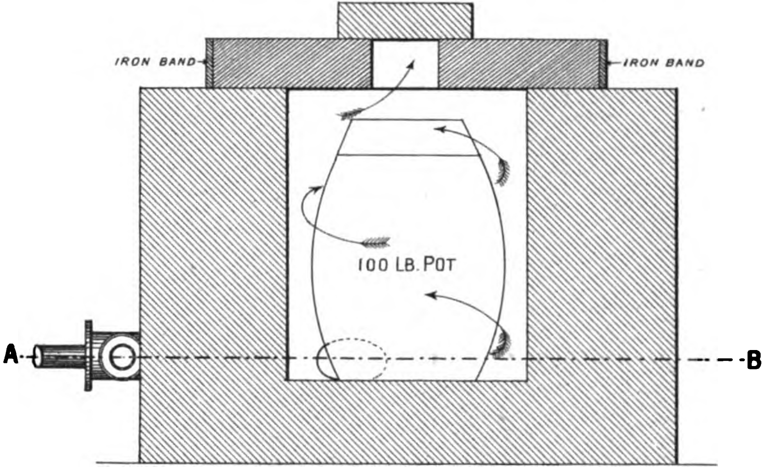
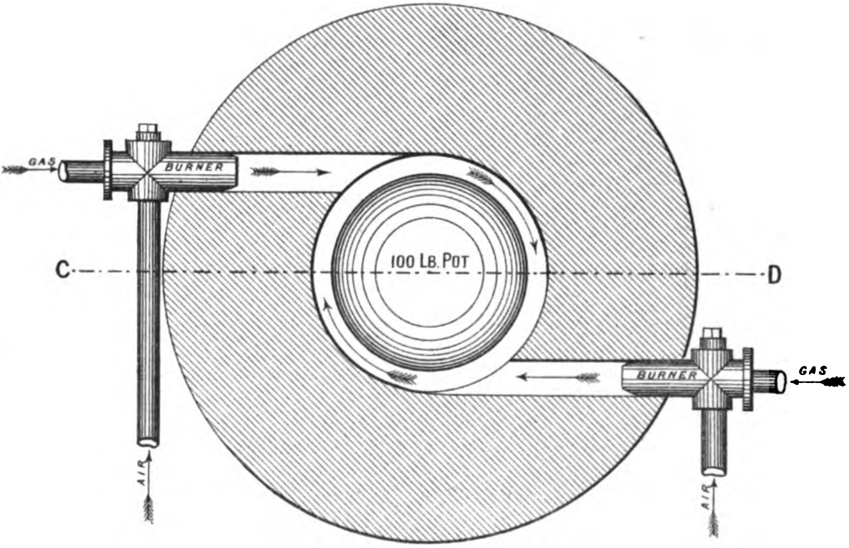
PLATE XXIII.

TO ILLUSTRATE MR. BURDETT LOOMIS'S PAPER ON FUEL GAS.

SPIRAL FLAME POT FURNACE,
FOR WATER GAS.



SECTION ON LINE C D



SECTION ON LINE A B

SCALE

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SECTION OF ELEVATION OF MASSICKS & CROOKE'S PATENT 3 PASS FIREBRICK STOVE 18'·0" DIAM., 60'·0" HIGH.

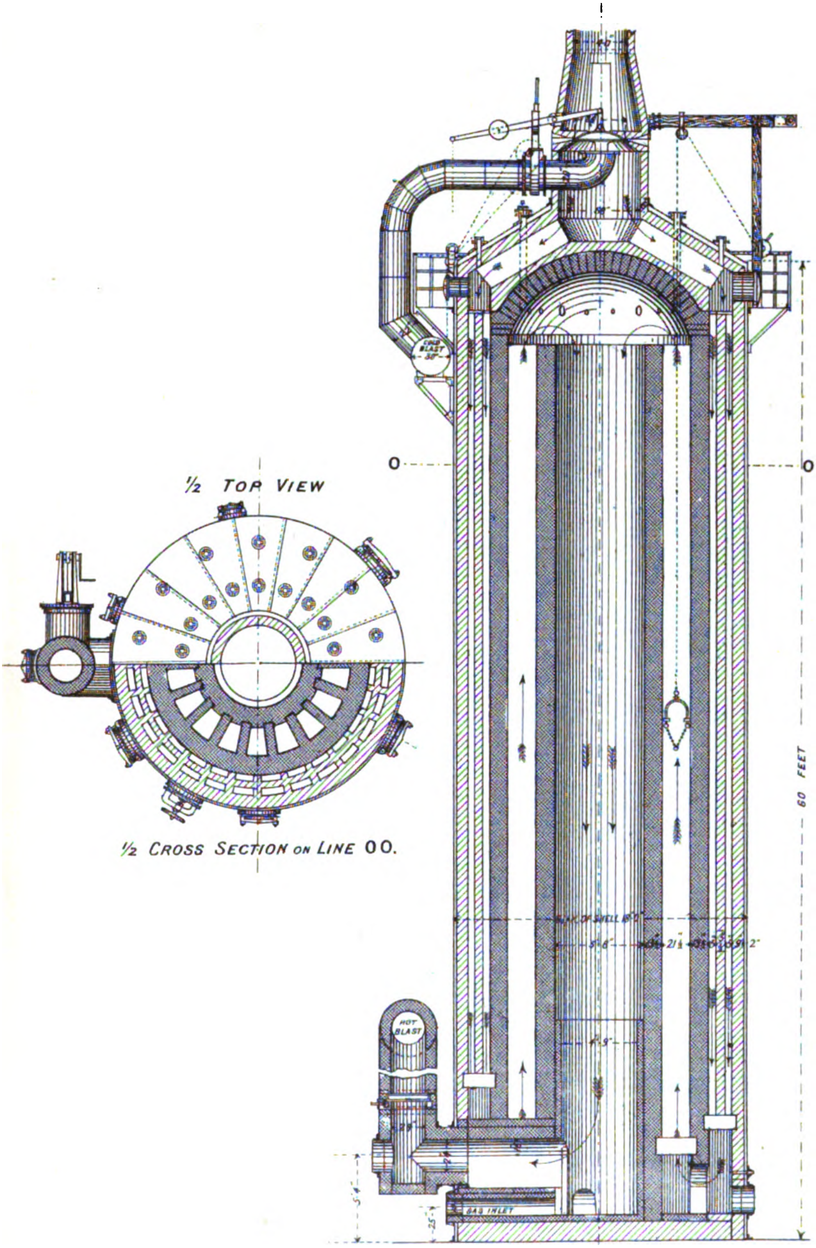

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PLATE XXV.

PRACTICE IN METALLURGY.

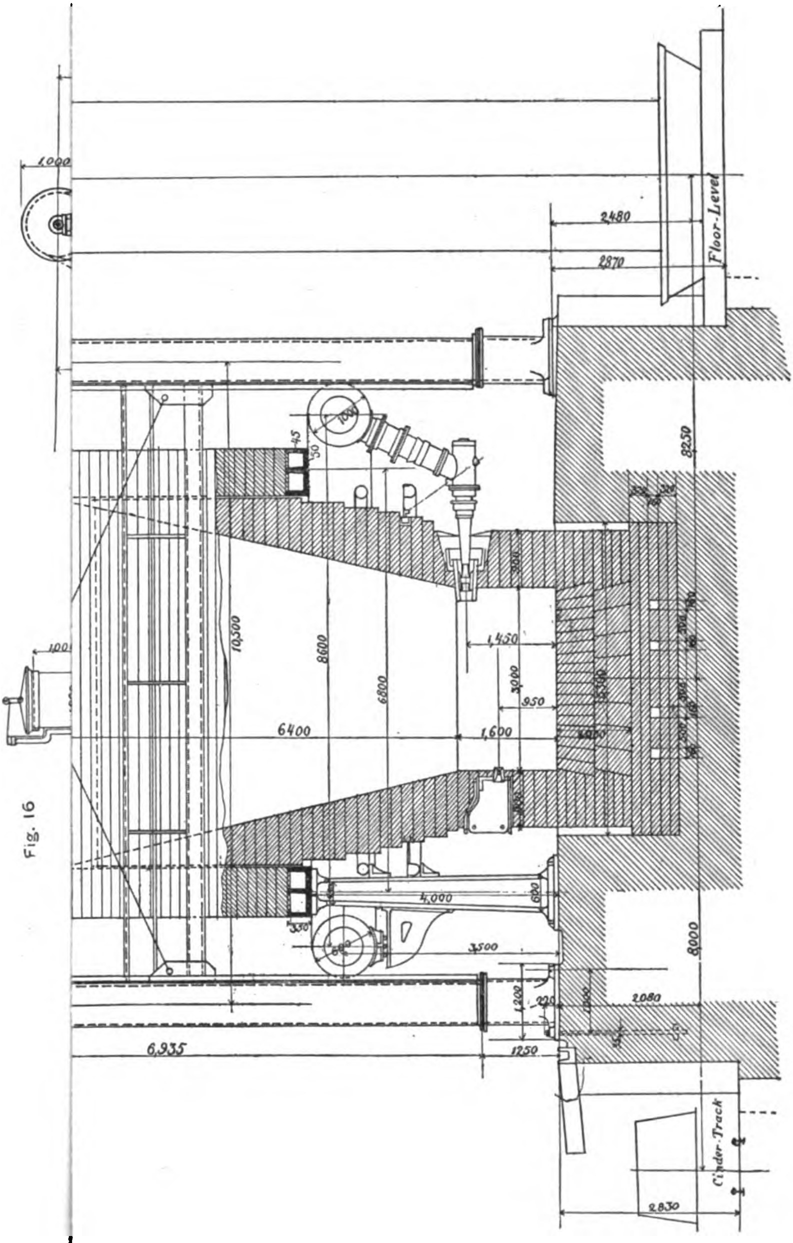
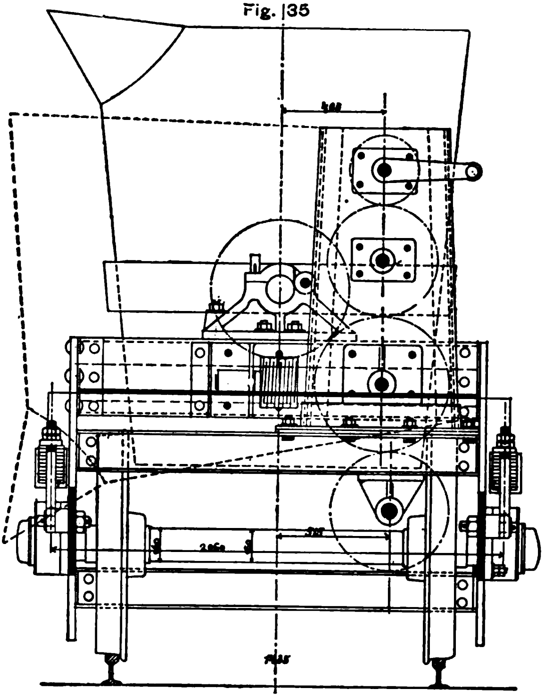
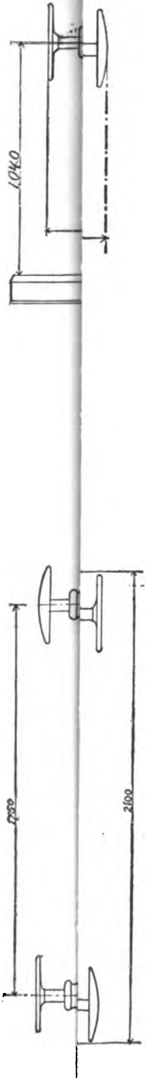


Fig. 16

Fig. 135





TEN-TON LADLE-CAR AT THE HÖRDE WORKS, WESTPHALIA.

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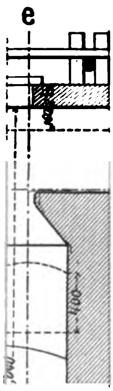

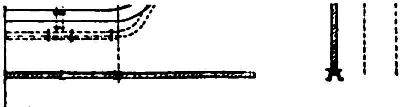

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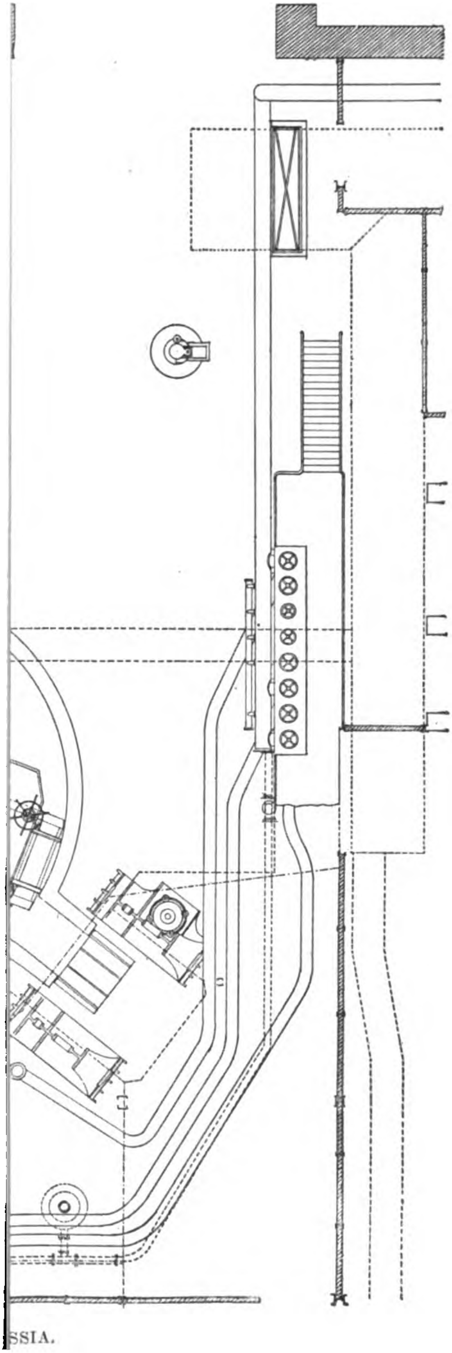
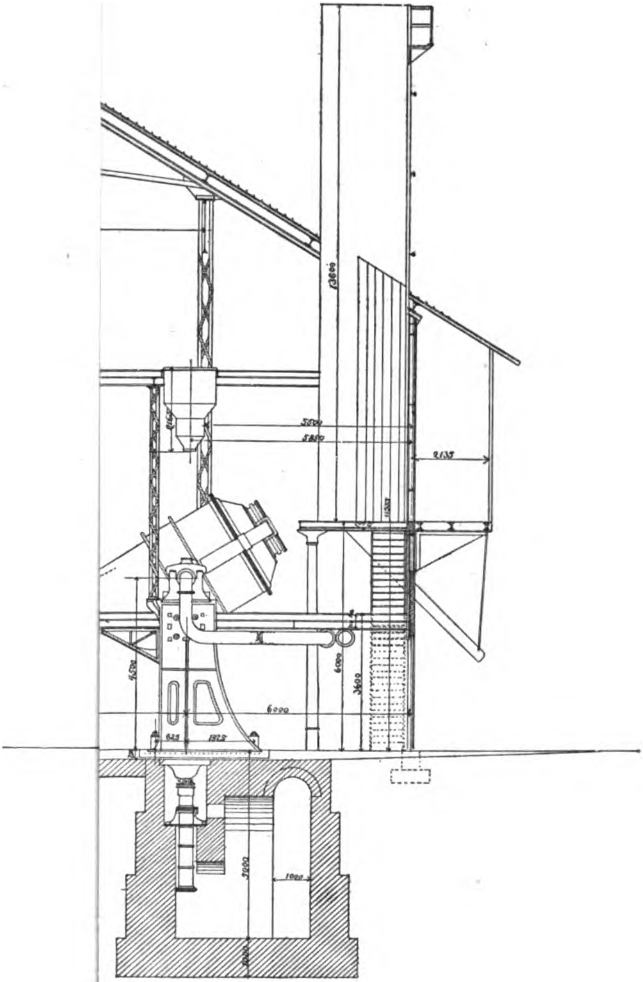
TO MAN PRACTICE IN METALLURGY.



SSIA.

ROGRESS OF

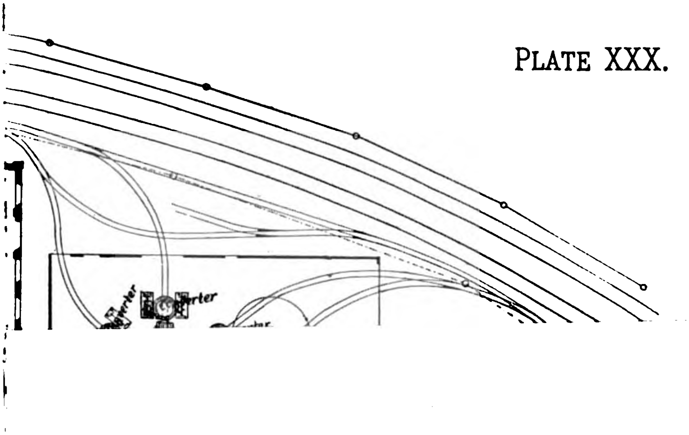
PLATE XXIX.



SSIA.

RACTICE IN METALLURGY.

PLATE XXX.



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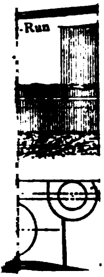
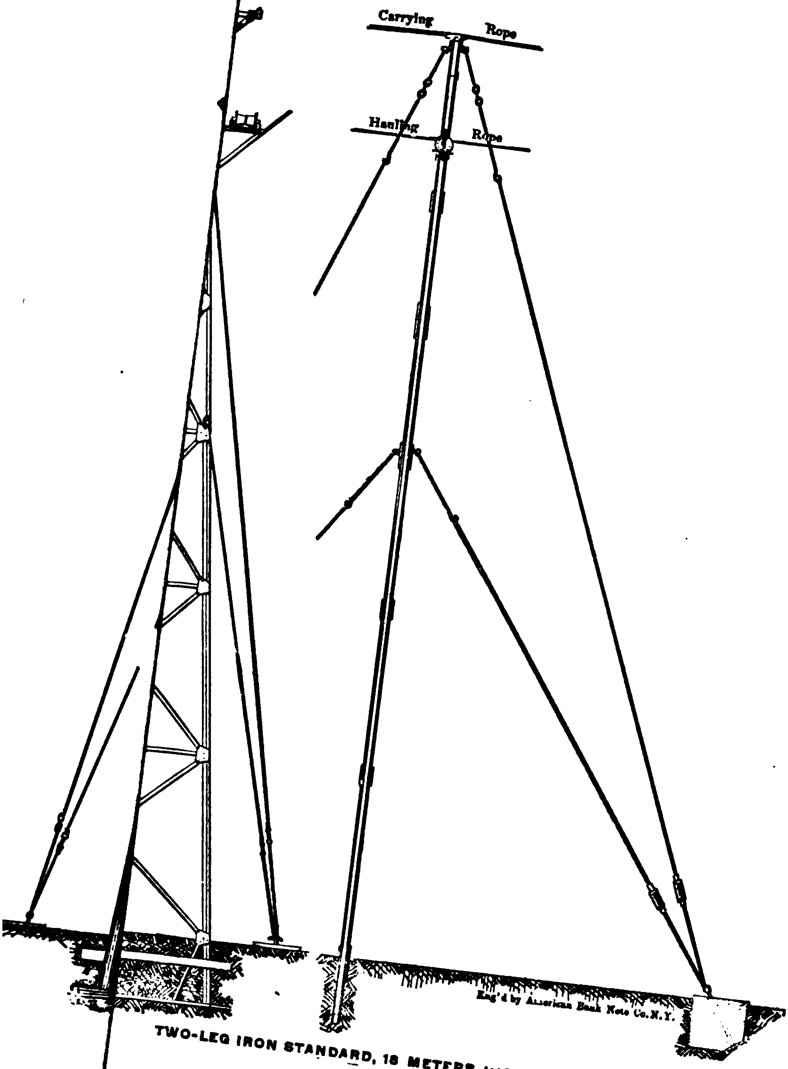


Fig. 2.



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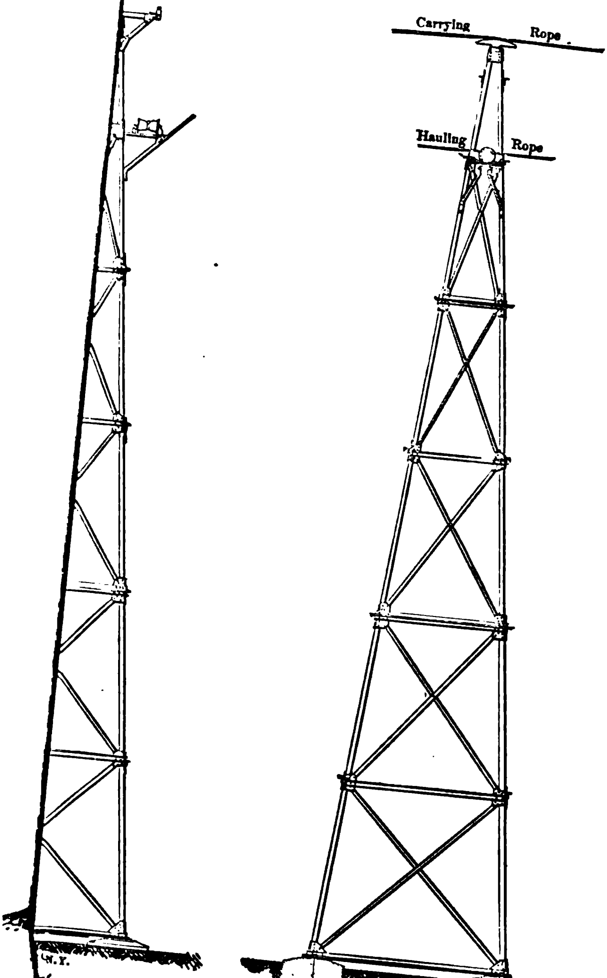
TWO-LEG IRON STANDARD, 18 METERS HIGH

PLATE XXXIV.

WIRE ROPEWAYS."

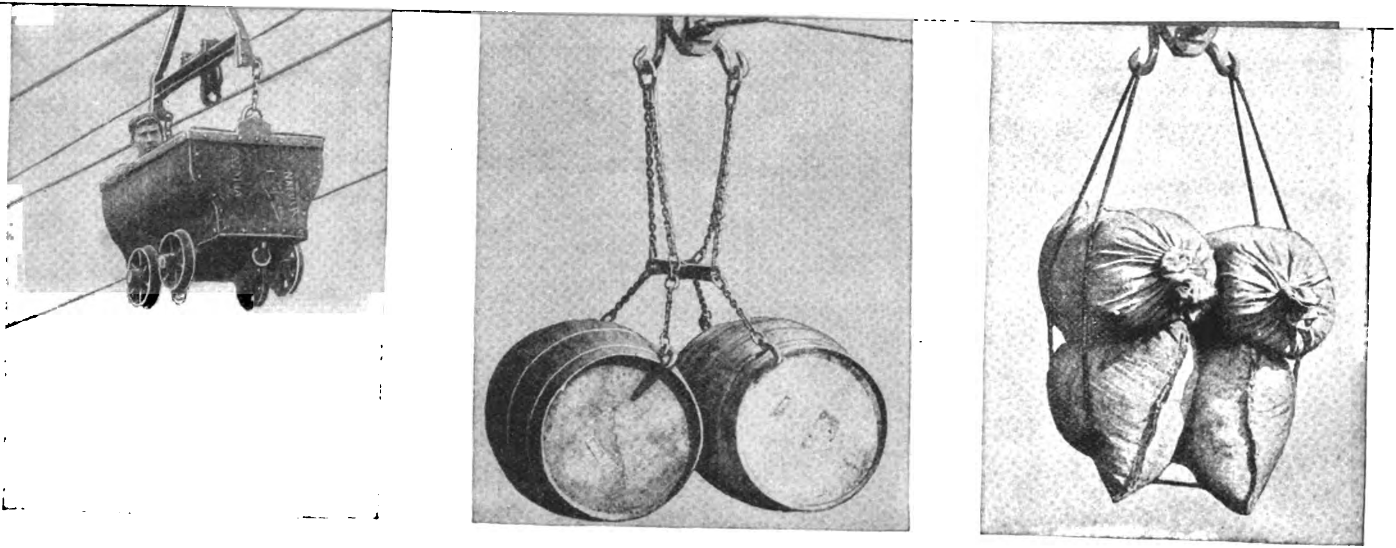
Fig. 4.



4-LEG IRON STANDARD, 18 METERS HIGH.

TO ILLUSTRATE MR. J. POHLIG'S PAPER ON "AERIAL WIRE ROPEWAYS."

Fig. 5.

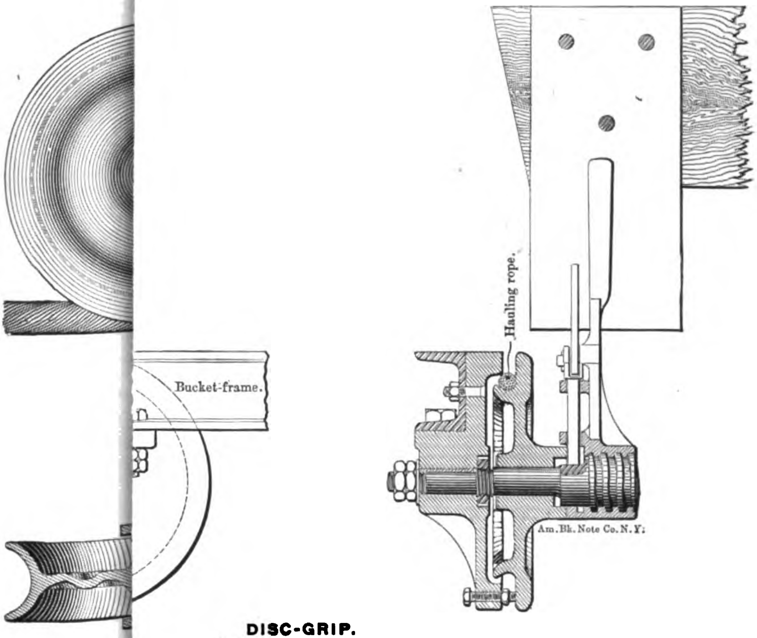


Carriers for the "Otto" Aerial Ropeways.

PLATE XXXVI.

WIRE ROPEWAYS."

Fig. 8.

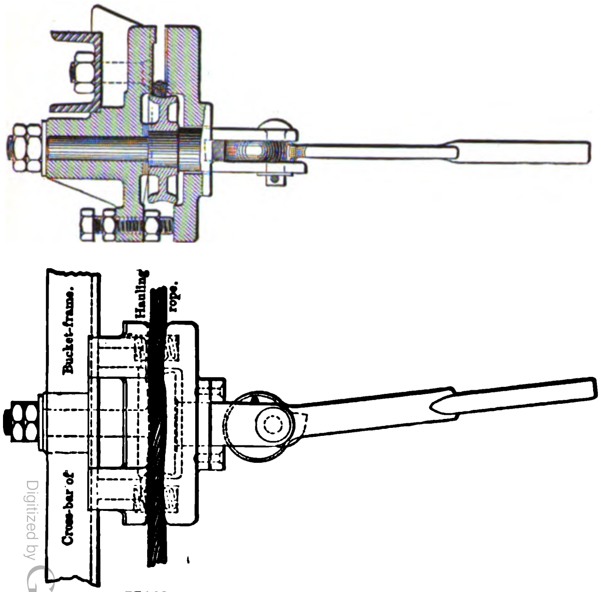


DISC-GRIP.
Scale, 1½ inches = 1 foot.

PLATE XXXVII.

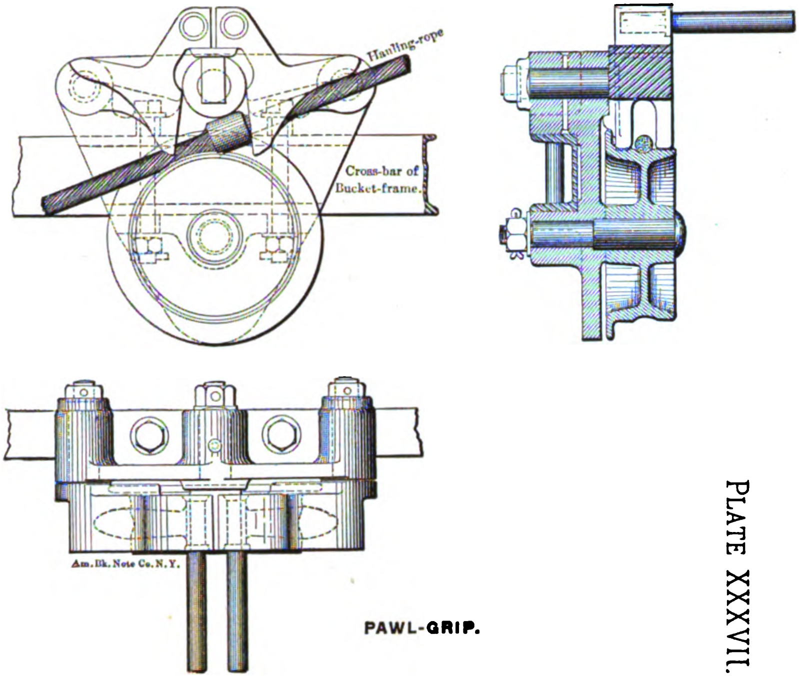
TO ILLUSTRATE MR. J. POHLIG'S PAPER ON "AERIAL WIRE ROPEWAYS."

Fig. 9.



FRICTION-GRIP WITH CORRUGATED JAWS.

Fig. 10.



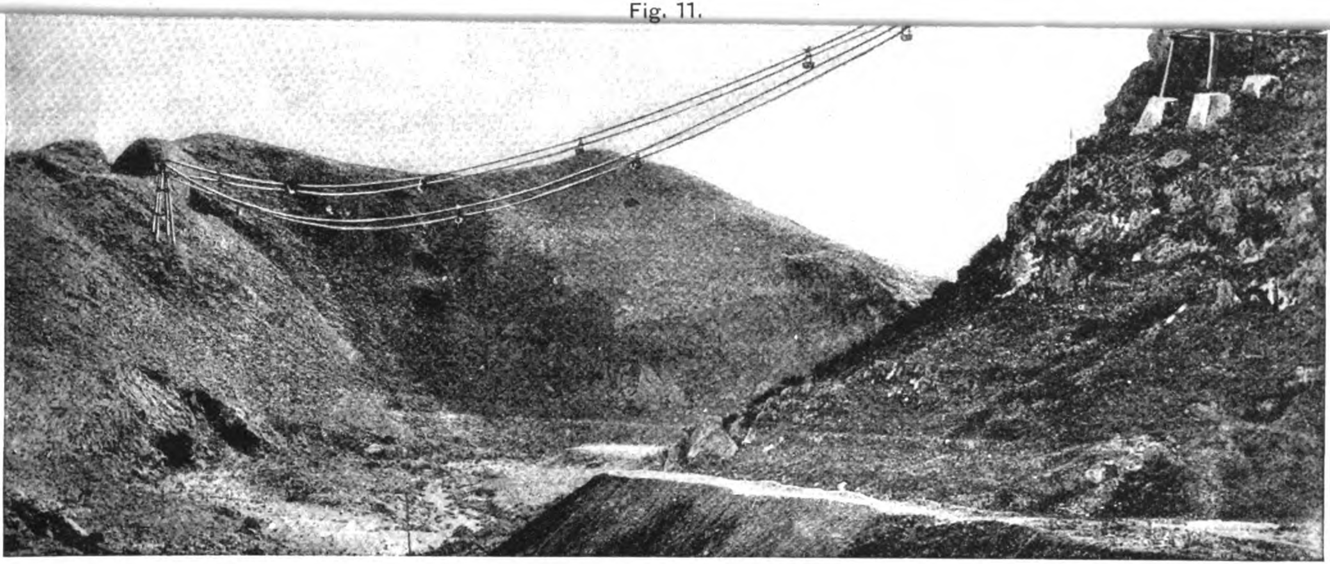
Am. Bk. Note Co. N. Y.

PAWL-GRIP.

PLATE XXXVIII.

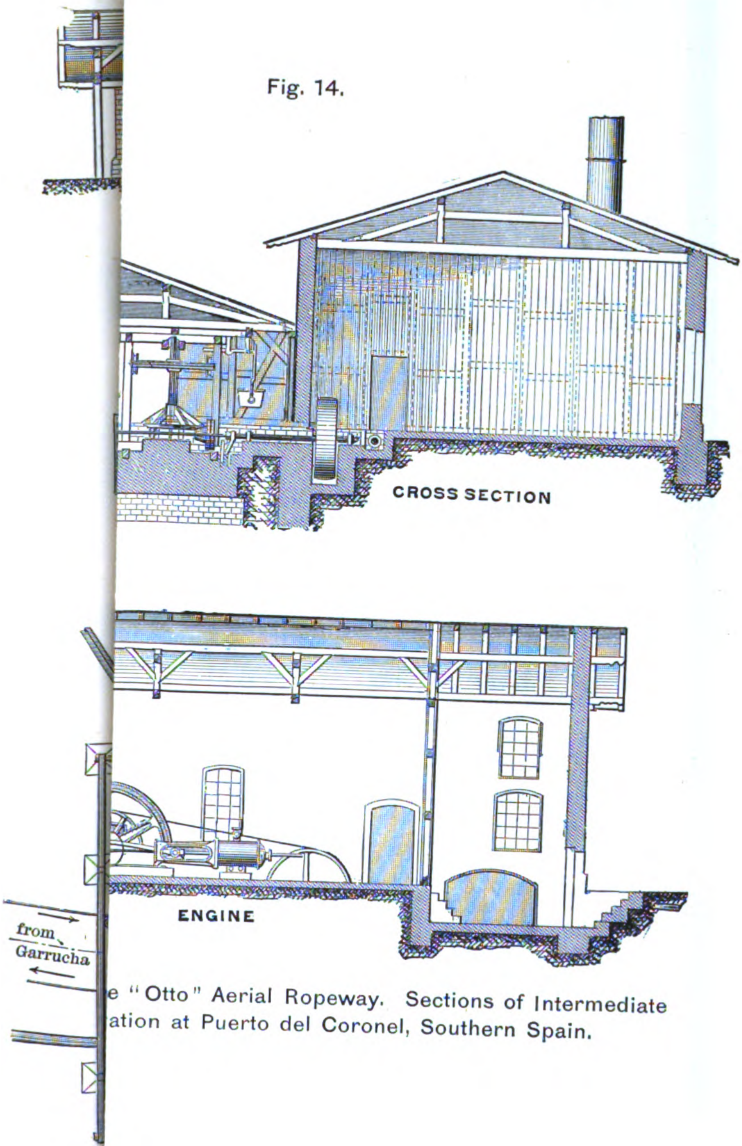
TO ILLUSTRATE MR. J. POHLIG'S PAPER ON "AERIAL WIRE ROPEWAYS."

Fig. 11.



Garrucha Line of the "Otto" Aerial Ropeway, Southern Spain. Span of 280 Meters (920 feet).

Fig. 14.

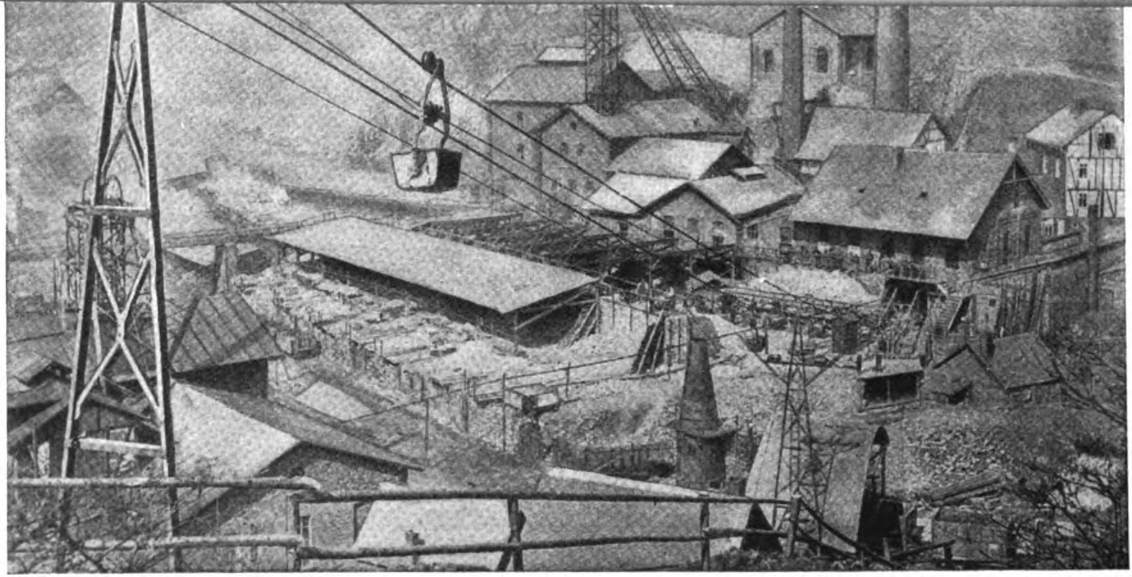


e "Otto" Aerial Ropeway. Sections of Intermediate
ation at Puerto del Coronel, Southern Spain.

Gar
Int

TO ILLUSTRATE MR. J. POHLIG'S PAPER ON "AERIAL WIRE ROPEWAYS."

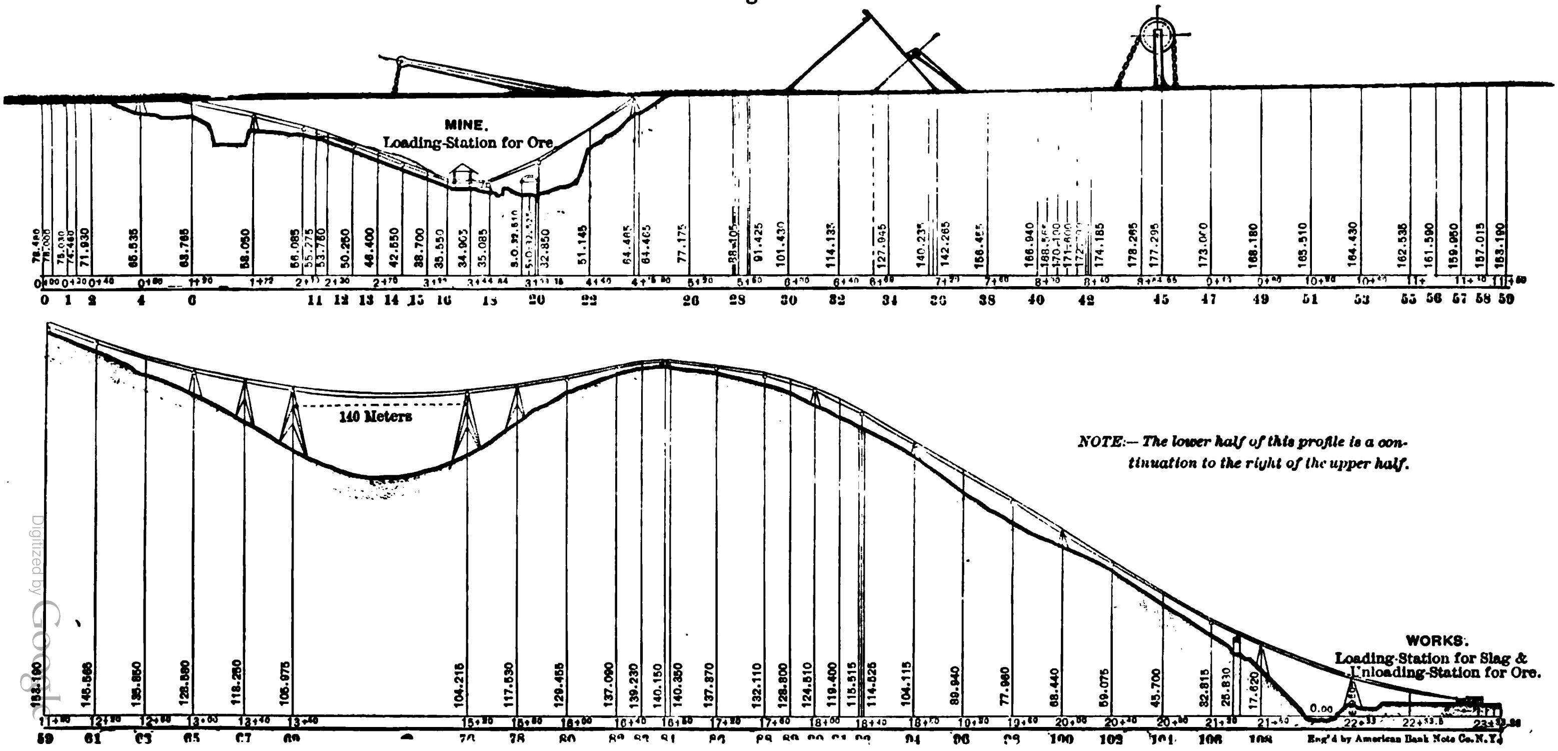
Fig. 15.



Marienhütte Line of the "Otto" Aerial Ropeway, near Siegen, Westphalia. View at the Mine, showing the Loading-Station for Ore and Intermediate-Station for Slag.

TO ILLUSTRATE MR. J. POHLIG'S PAPER ON "AERIAL WIRE ROPEWAYS."

Fig. 16.



NOTE:—The lower half of this profile is a continuation to the right of the upper half.

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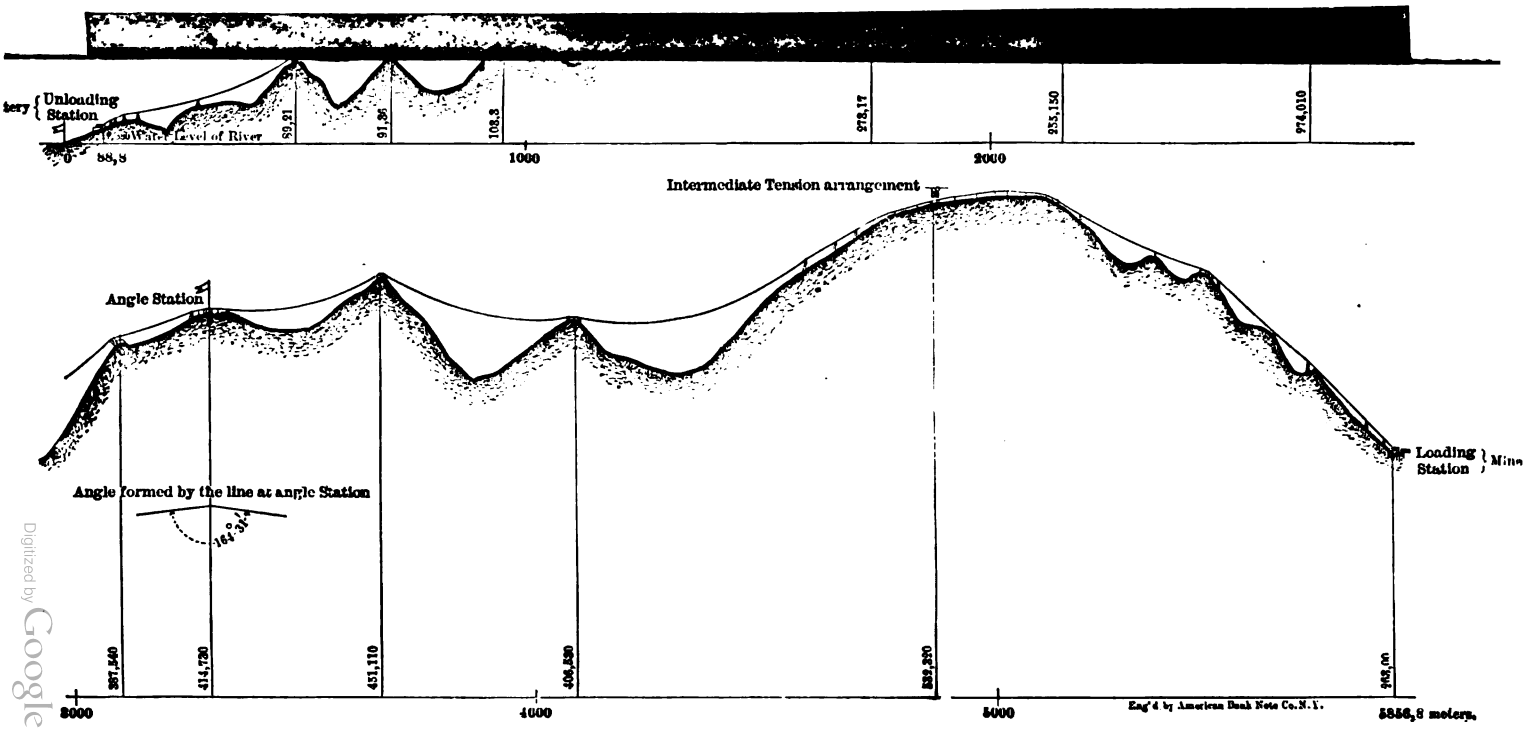
TO ILLUSTRATE MR. J. POHLIG'S PAPER ON "AERIAL WIRE ROPEWAYS.

Fig. 19.



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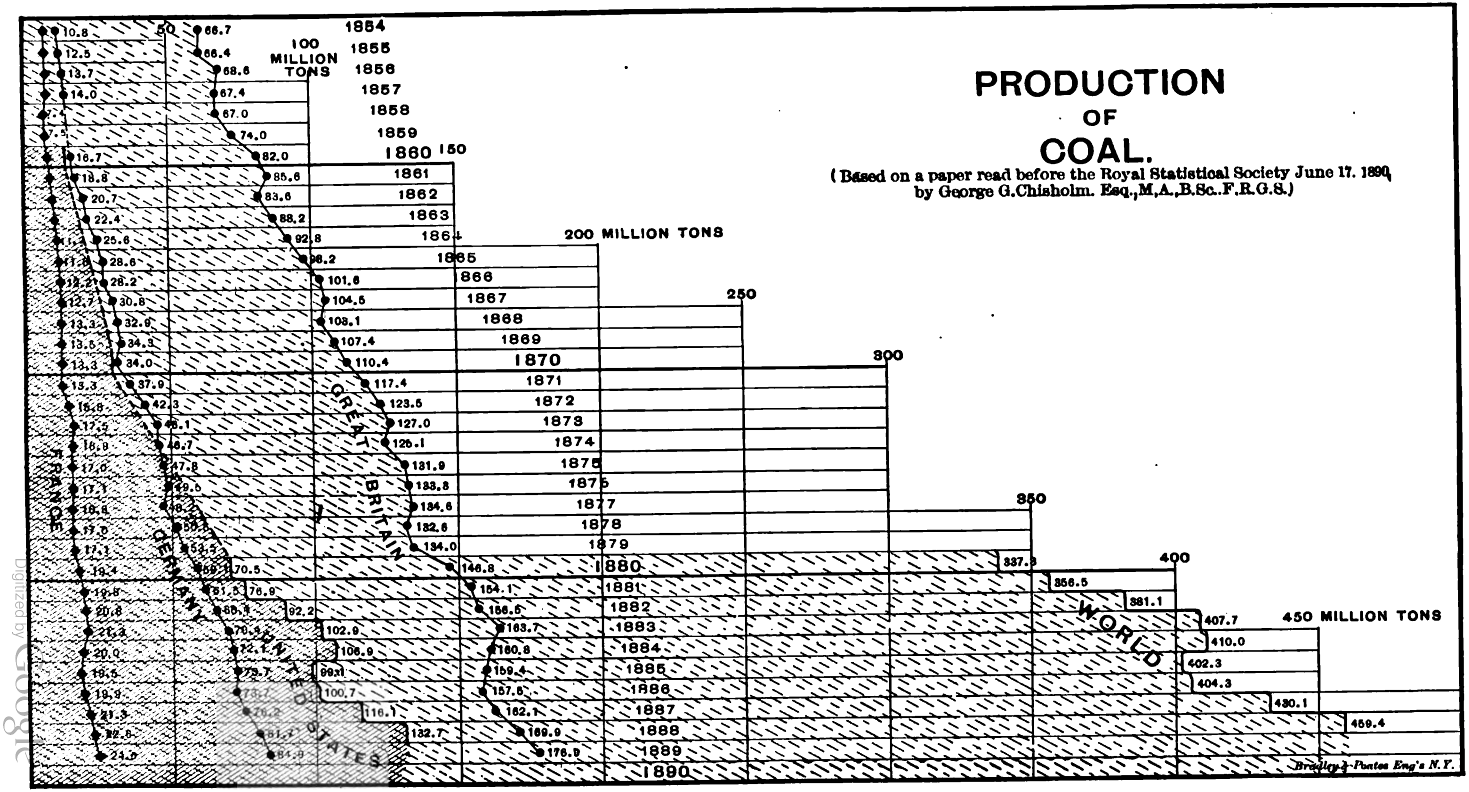
TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.



PRODUCTION OF COAL.

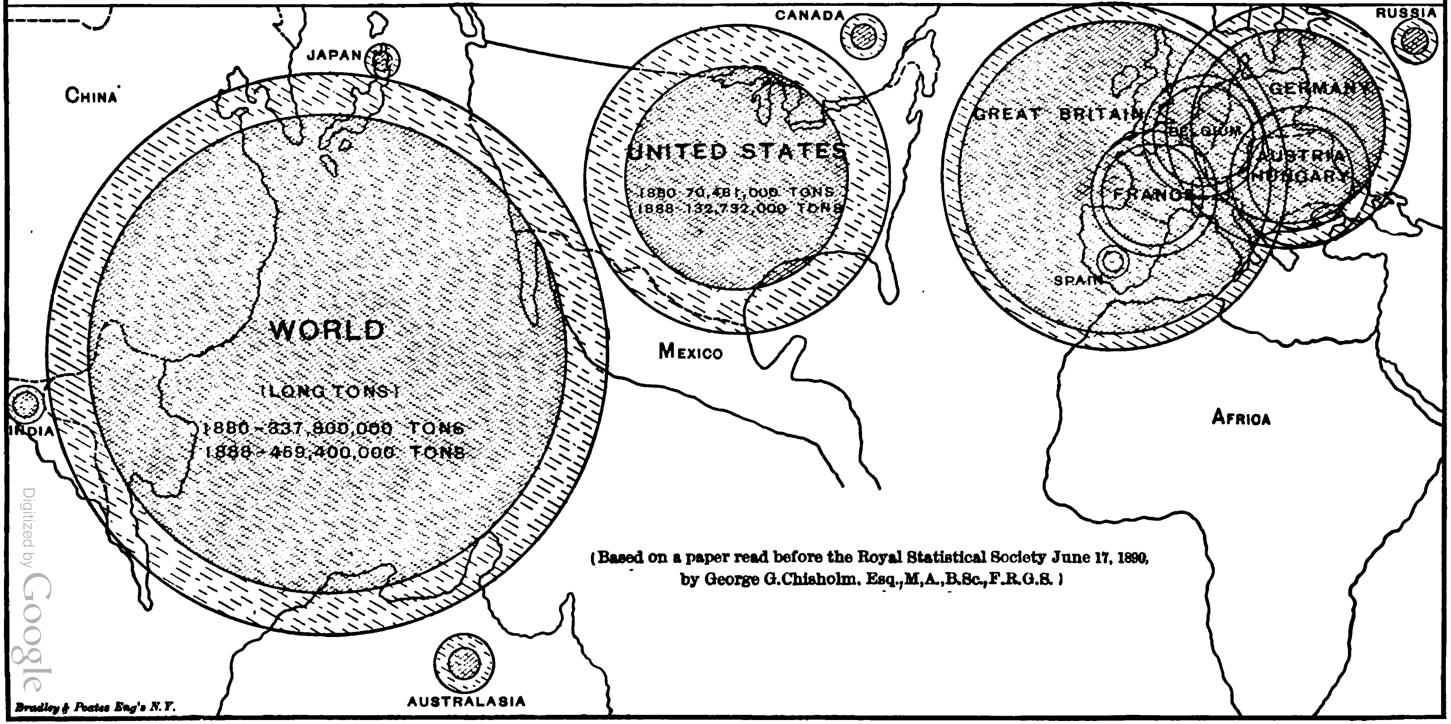
(Based on a paper read before the Royal Statistical Society June 17. 1890, by George G. Chisholm. Esq., M.A., B.Sc., F.R.G.S.)

PLATE XLIII.

PLATE XLIV.

TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.

PRODUCTION OF COAL BY COUNTRIES, 1880 AND 1888.



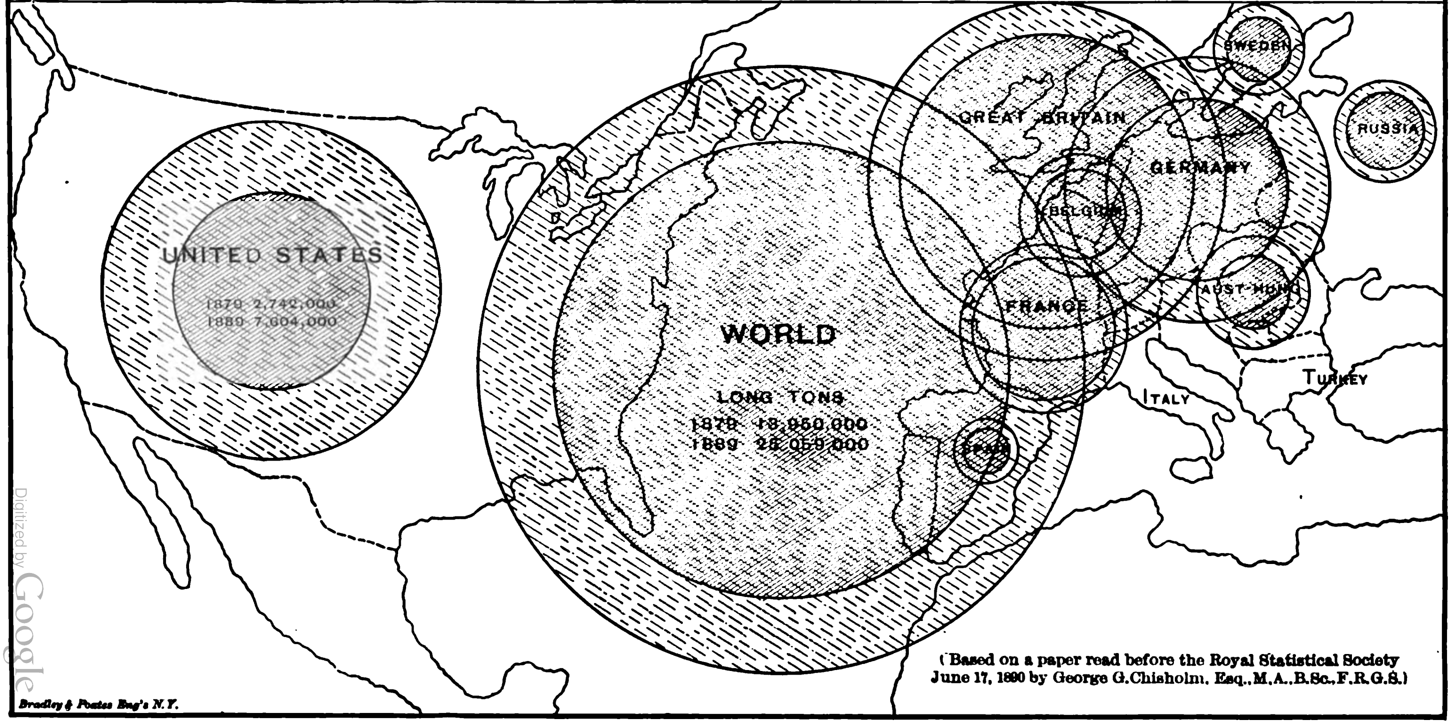
(Based on a paper read before the Royal Statistical Society June 17, 1890, by George G. Chisholm, Esq., M.A., B.Sc., F.R.G.S.)

Bradley & Poates Eng's N.Y.

PLATE XLV.

TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.

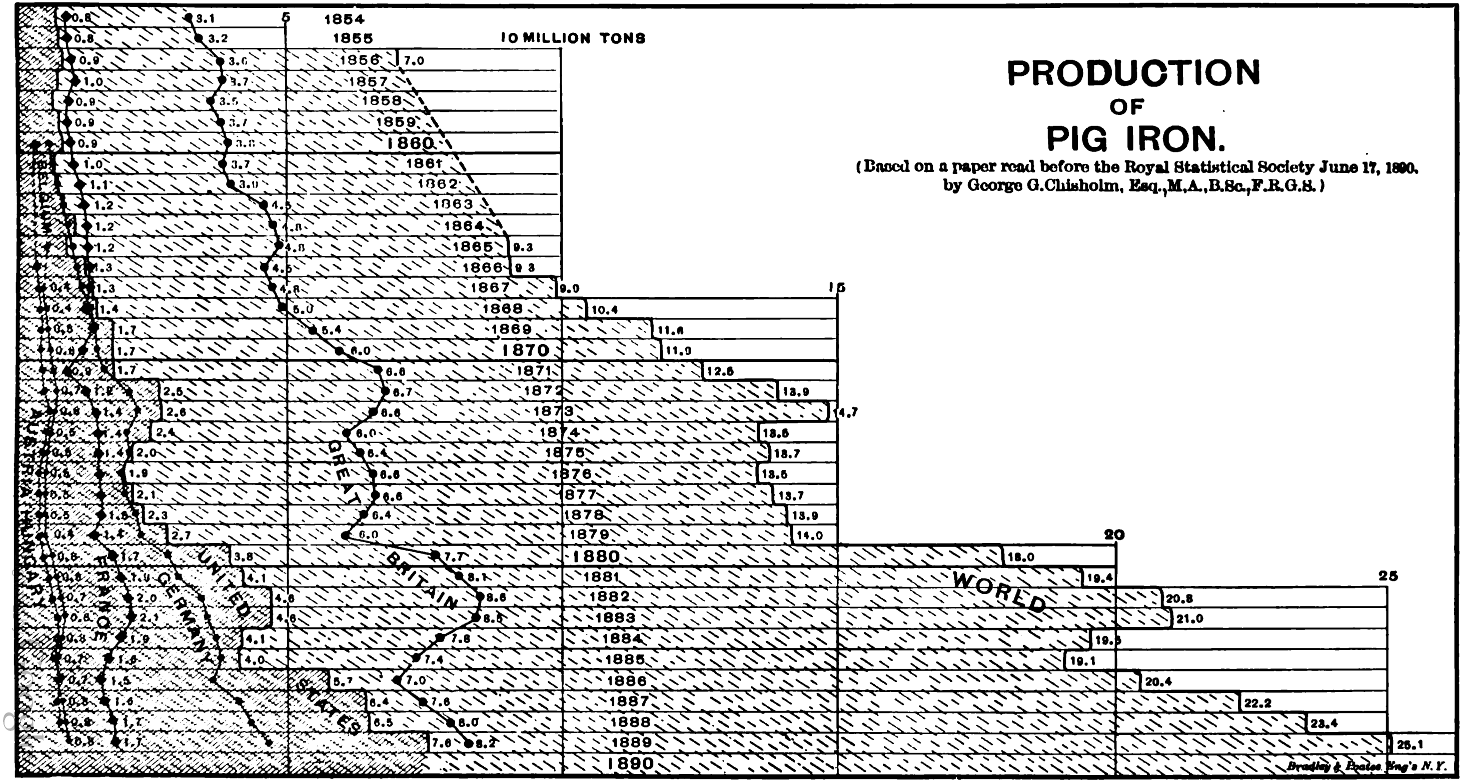
PRODUCTION OF PIG IRON BY COUNTRIES, 1879 AND 1889.



(Based on a paper read before the Royal Statistical Society June 17, 1890 by George G. Chisholm, Esq., M.A., B.Sc., F.R.G.S.)

Bradley & Poates Eng's N.Y.

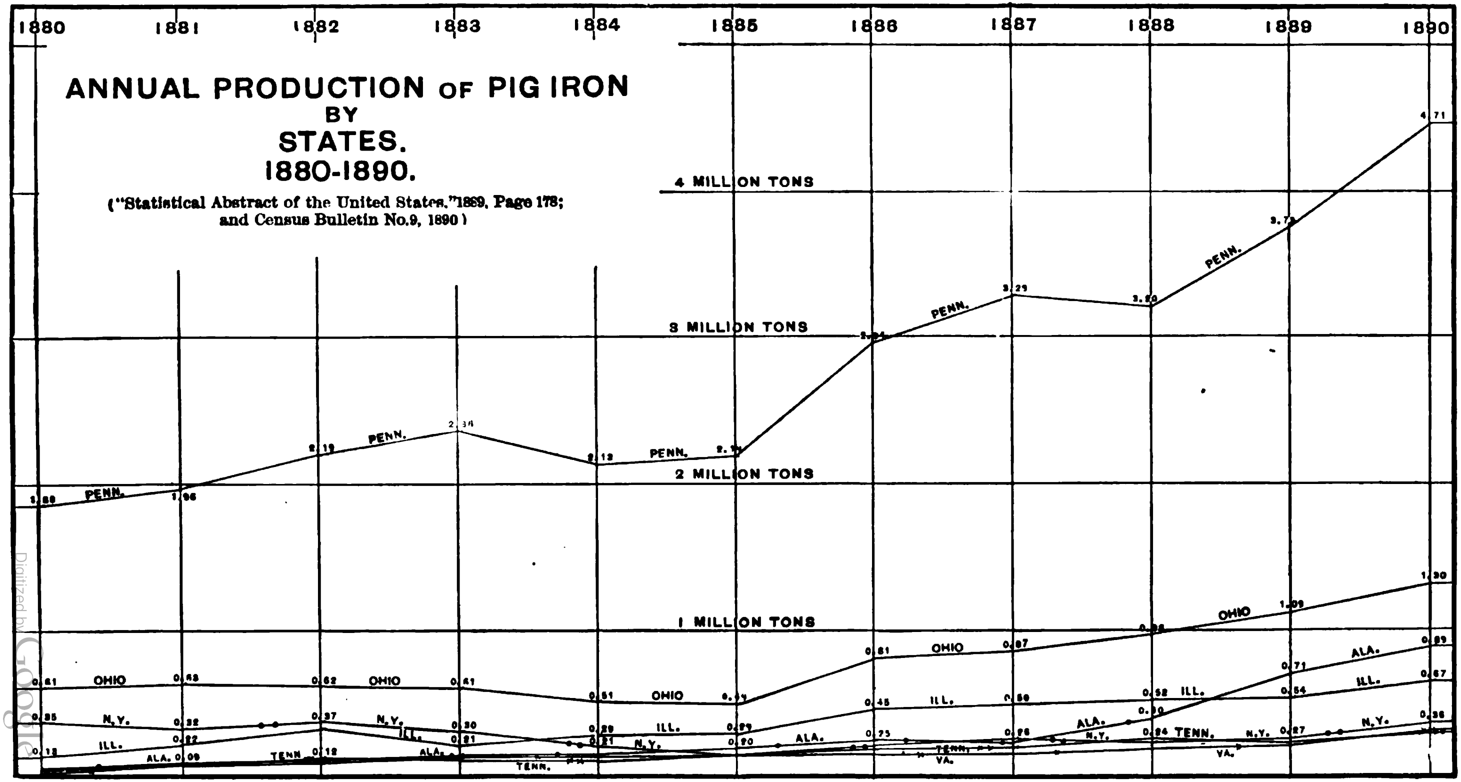
TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.



PRODUCTION OF PIG IRON.

(Based on a paper read before the Royal Statistical Society June 17, 1890. by George G. Chisholm, Esq., M.A., B.Sc., F.R.G.S.)

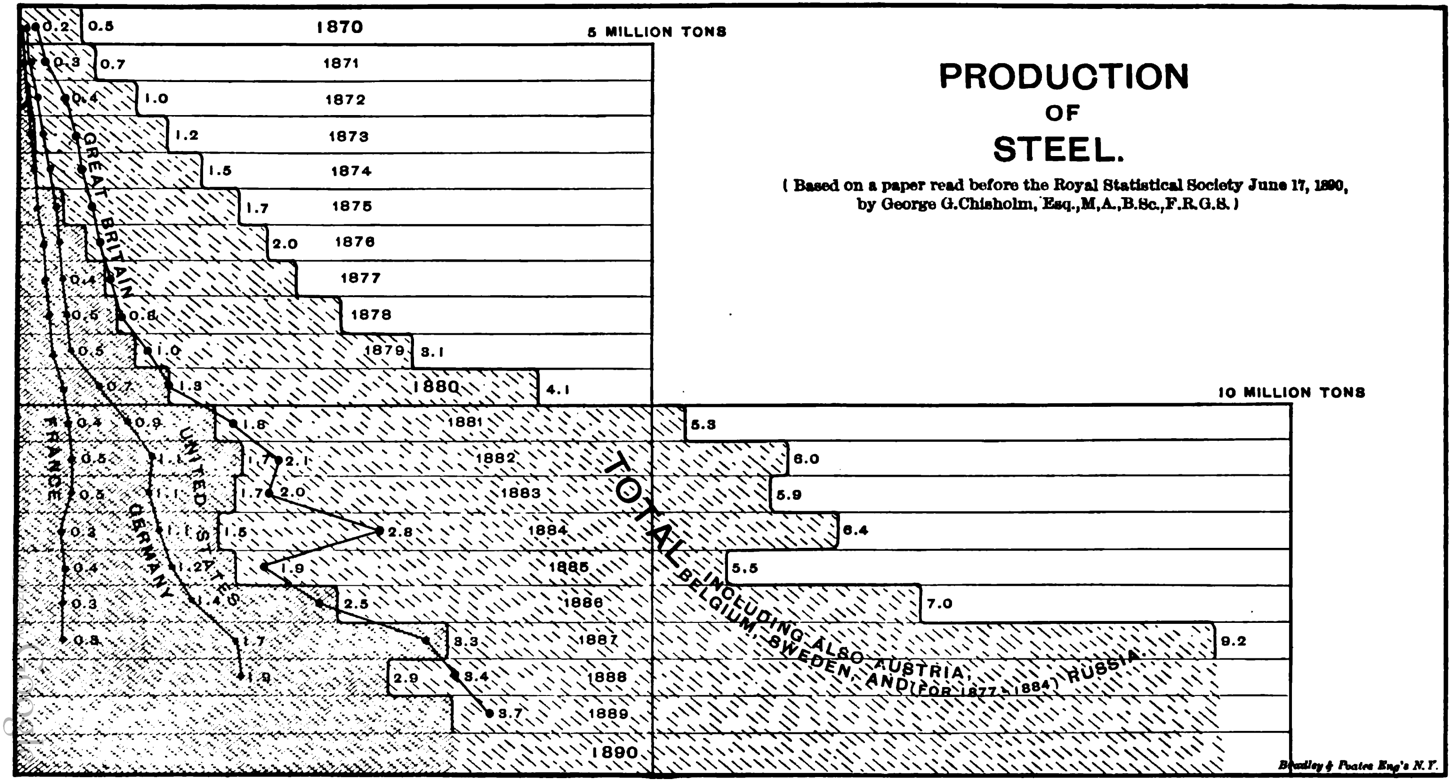
TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.



ANNUAL PRODUCTION OF PIG IRON
BY
STATES.
1880-1890.

("Statistical Abstract of the United States," 1889, Page 178;
and Census Bulletin No.9, 1890)

TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.



PRODUCTION
OF
STEEL.

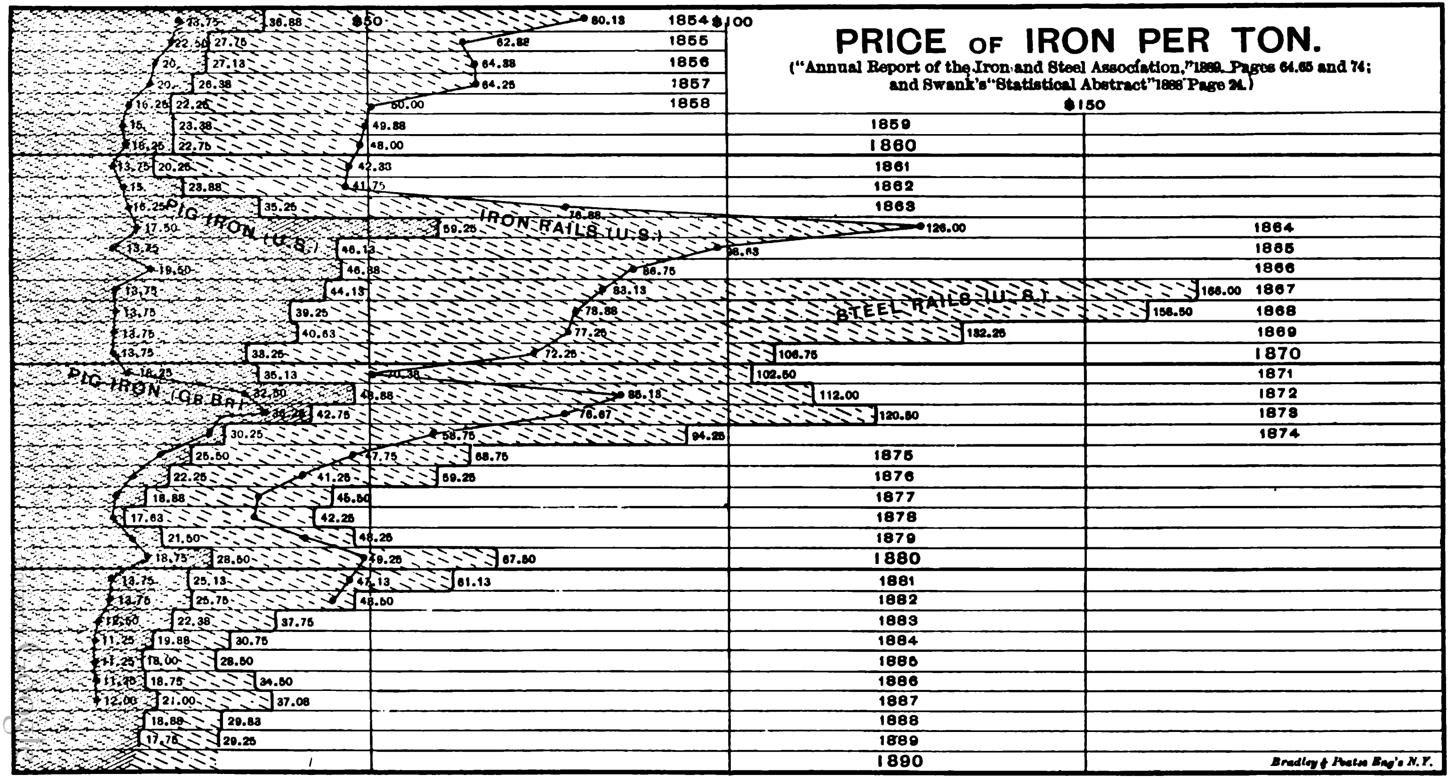
(Based on a paper read before the Royal Statistical Society June 17, 1890, by George G. Chisholm, Esq., M.A., B.Sc., F.R.G.S.)

Bradley & Poates Eng's N.Y.

PLATE XLVIII.

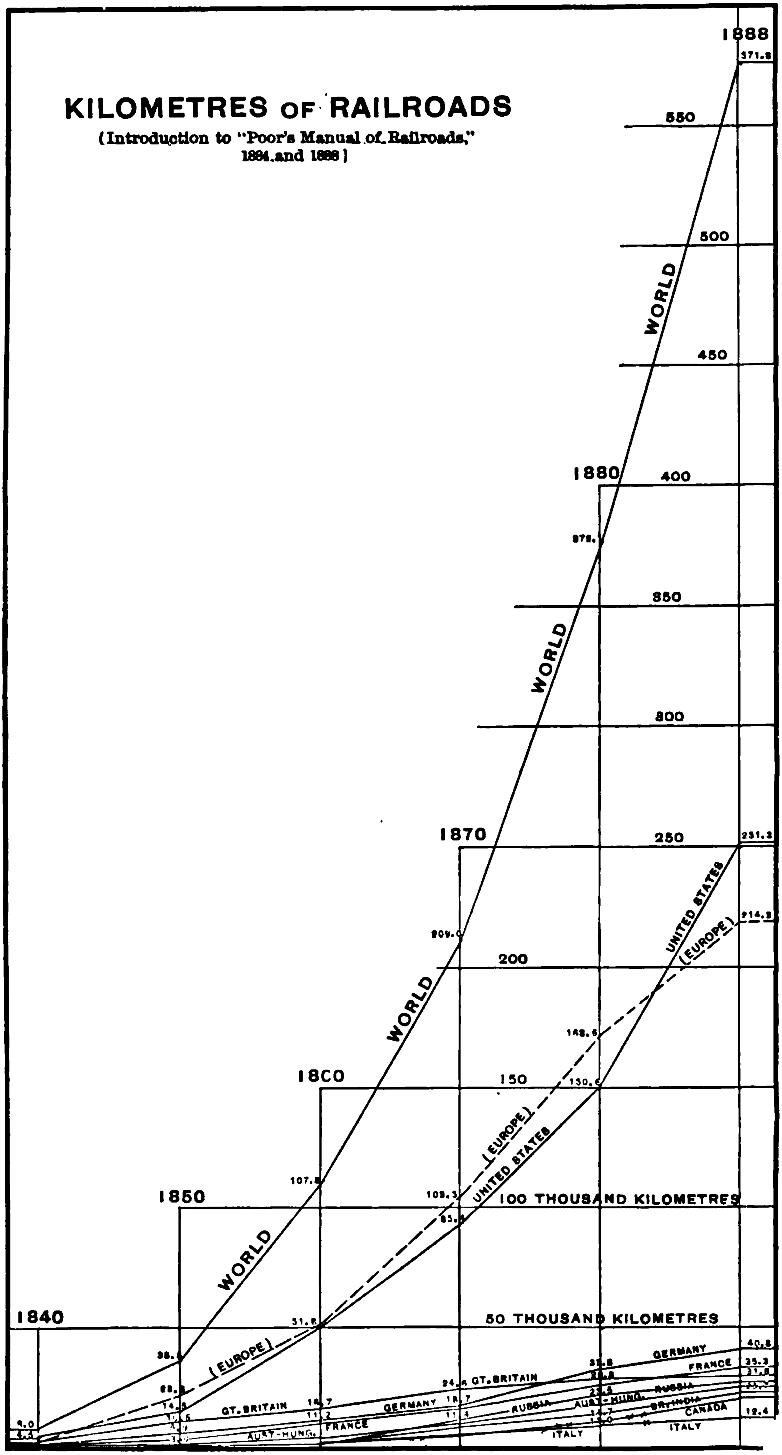
TO ILLUSTRATE MR ABRAM S. HEWITT'S ADDRESS.

PLATE XLIX.


PRICE OF IRON PER TON.

("Annual Report of the Iron and Steel Association," 1889. Pages 64.65 and 74; and Swank's "Statistical Abstract" 1888 Page 24.)

PLATE L.



KILOMETRES OF RAILROADS

(Introduction to "Poor's Manual of Railroads," 1884 and 1888)

TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.

PLATE LI.

TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.

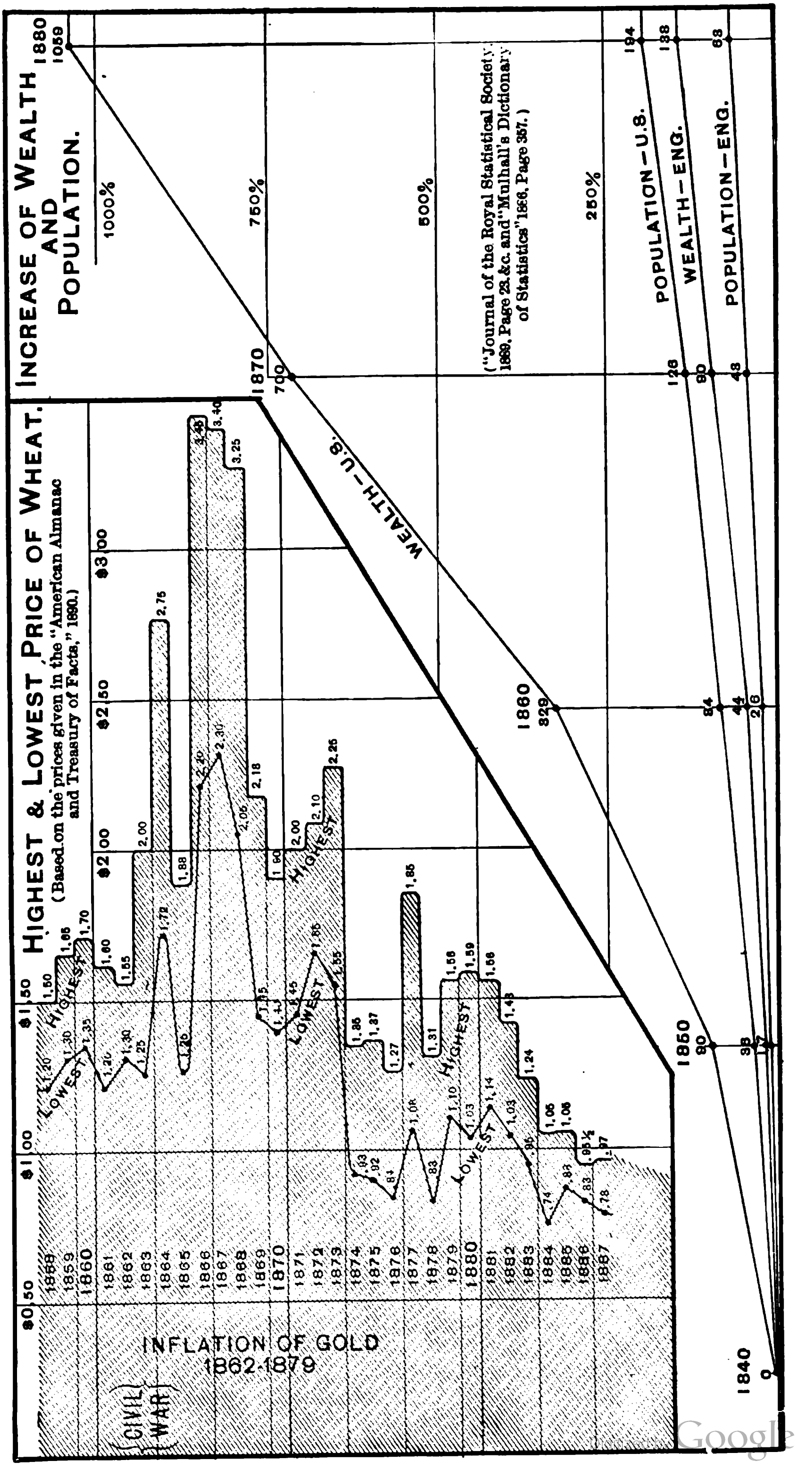
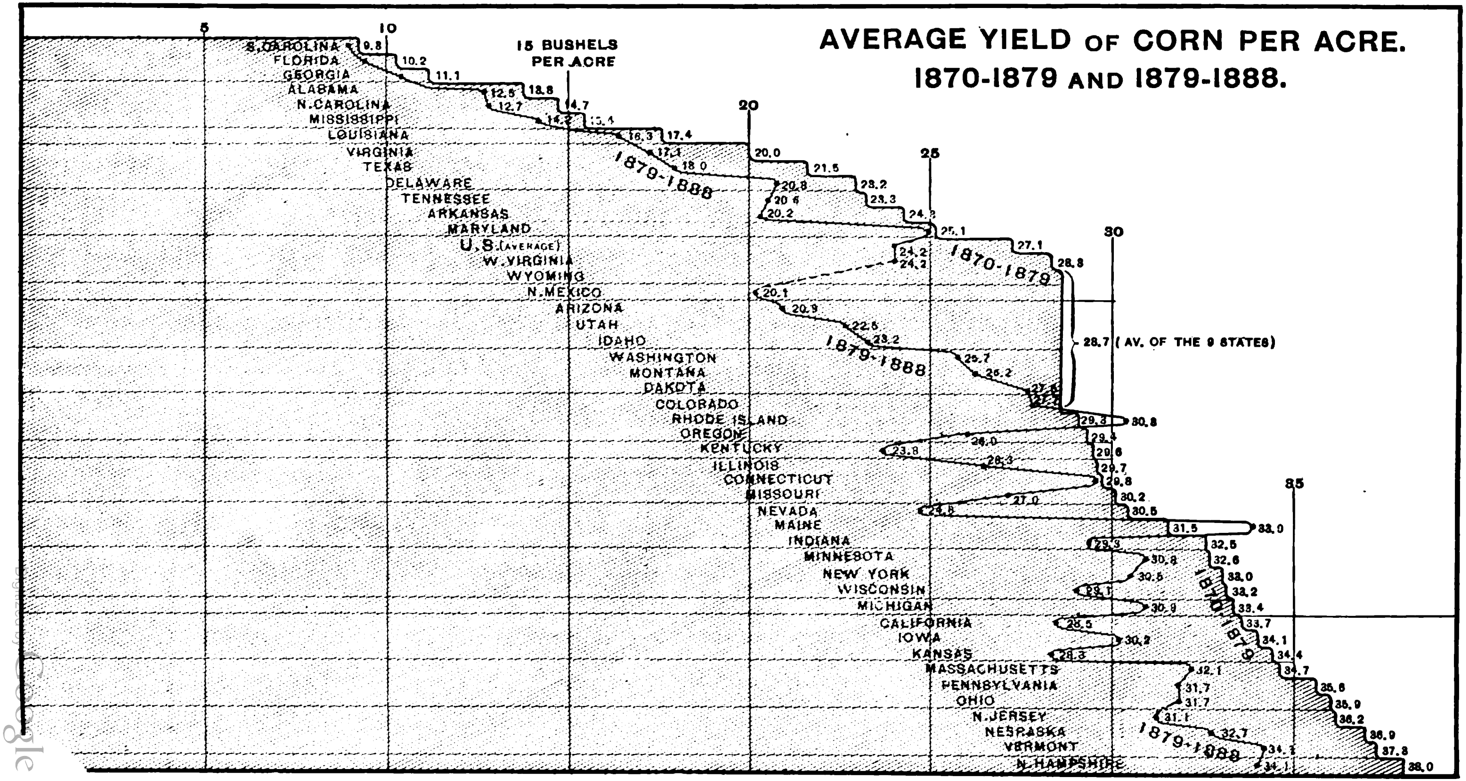


PLATE LII.

TO ILLUSTRATE MR. ABRAM S. HEWITT'S ADDRESS.



AVERAGE YIELD OF CORN PER ACRE. 1870-1879 AND 1879-1888.

NOTES

ON THE PROGRESS OF THE

HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

II.—1890.

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ABSTRACTORS.

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IRON ORES.

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I.—*OCCURRENCE AND COMPOSITION.*

Iron Ores of France and Algeria.—H. Carnot [*] has tabulate the analyses of iron ore from France, Algeria, and Tunis, made i the assay office of the Paris School of Mines from 1845 to 188 Altogether 1796 analyses are given. The samples were furnished b seventy-eight departments, including the three departments of Alger and Tunis. The analyses are arranged, under the heads of the differe departments, in alphabetical order. To each analysis a note is appende describing the geological occurrence of the ore.

Bog Iron Ores of Saxony.—B. Turley [†] describes the bog iro ores of the district adjacent to Annaburg, Saxony. These ores occur i somewhat thin beds, the percentage of iron varying from as low as 2 per cent. to about 42 per cent. In this latter case the ore containe 3·2 per cent. of phosphorus. The deposits have not been worked sinc 1875.

An estimate based on the payments made in previous years, plac the cost of 10 tons of ore at—

	£	s.	d.
Mining and washing the ore	1	0	0
Carting to Annaburg railway station	1	0	0
Wages paid for loading	0	2	6
Compensation for damage to ground	0	1	0
	£2	3	6

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[*] *Annales des Mines*, vol. xviii. pp. 1–163.

[†] *Berg- und Hüttenmännische Zeitung*, vol. xlix. pp. 120–121.

At the present time the ore is largely used for mending the roads and for the construction of walls and buildings.

Oolitic Iron Ore.—The occurrence of oolitic iron ore, Minette, in Lorraine, Luxemburg, and Eastern France is discussed by Wandesleben.* The district in which these ore deposits are found is somewhat more than 60 miles in length by 11 in width. Of this, the German portion has a length of rather less than 40 miles and a breadth of about 8. In nearly the whole of this large district the deposits are of adequate size to render them of commercial importance. The district consists practically of a gradually rising range of hills on the left bank of the Moselle, the formation being the brown Jura, or lower Dogger, and the upper Lias. A number of faults crossing the country in a SW.–NE. direction have an important bearing on the iron ore deposits. The iron in the ore is probably present for the greater part in the form of $2Fe_2O_3, 3H_2O$. The granules of ore are mainly round or elliptical, and of about the size of the head of a pin. The percentage of iron varies from 30 to 40, and in exceptional instances reaches 45; usually, however, it is from 32 to 38. The phosphorus is from 0·5 to 2·0 per cent.

Iron pyrites occurs in variable quantities, sometimes being present in the form of veins running through the ore. As a rule the percentage of sulphur is less than that of the phosphorus also present. The percentage of lime, alumina, silica, &c., varies greatly at different places.

The ore occurs in the form of a number of beds of very variable thickness; the total thickness of the four main beds at Esch, Luxemburg, is about 66 feet.

The following are analyses of ore from different parts of the district described:—

Locality.	Iron.	Lime.	Alumina.	Silica.
Esch, brown ore	38–40	6–8	7–8	13–15
Esch, grey ore	30–34	14–20	4–6	7–8
Rodingen, grey ore . . .	40–42	3	7	15–20
Esch, red-lime bed . . .	35–43	5–12	5–6	8–9
Oettingen, red-sand bed . .	28–32	large traces	...	25–40
Ars	28–30	8–12	10	18–20

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* *Stahl und Eisen*, vol. x. pp. 677–690, with map.

The "red-lime bed" is the one which is considered to yield the be
variety of ore.

The Minetté is found in its greatest thickness in Luxemburg, an
it is here, therefore, that it has hitherto been chiefly developed.

The pillar-and-stall method of working is the one employed. I
Lorraine 88 per cent. of the total quantity of ore raised is obtained b
deep mining, and 12 per cent. by open-workings; in Luxemburg, o
the other hand, 40 per cent. of the ore raised is derived from ope
workings.

About 100 large blast furnaces derive their ore supplies from th
district of oolitic ore.

The Iron Ore Deposits at Berggiesshübel.—These deposits a
described by H. Müller.* Mining was, it is believed, first carried o
in the district in the year 1441. The ore, which is mainly magnetit
occurs in a series of beds varying from a few inches to about 36 feet i
thickness. Down to a depth of some 65 feet red and brown hæmatit
are found in some quantity, but when this depth is passed the ma
netite becomes by far the more important as regards quantity. Owin
to the presence of chlorite an average analysis of the magnetite show
13·6 per cent. of silica and 10 per cent. of lime. The only importa
ore deposits, from a commercial standpoint, are found in metamorph
Silurian slate.

Iron Ore in North Sweden.—The exploration for apatite-bearin
iron ores which has been conducted for some time at the expense o
the Government has yielded good results in Norrland, extensive deposi
of weathered iron ore having been found at numerous points. A
experimental smelting in the blast-furnace belonging to the Filipsta
School of Mines gave a pig iron with 9 to 13 per cent. of phosphoru
and a slag with as much as 18 per cent. of phosphoric anhydride. I
is hoped not only to supply the Swedish demand for basic slag, bu
also to export it to Northern Europe.†

Manganiferous Iron Ore at Tyrnowa.—The gneiss of th
northern Banat chain of mountains in South Hungary contains nin
beds of manganiferous limonite, known to extend for some 5 miles.

---

* *Ueber die Erzlagerstätten in der Umgebung von Berggiesshübel*, with map. Leipz
1890.

† *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 311.

‡ *Ibid.*, vol. xlix. pp. 349-350.

The average thickness of the ore-bearing gneiss is 560 feet, the thickness of the ore-beds being 82 feet. As a rule the beds dip at an angle of 60°.

The average composition of the ore is as follows:—

Fe_2O_3.	Mn_3O_4.	SiO_2.	H_2O.
10·8	20·0	48·0	3·0

Besides these, the ore contains 18·0 per cent. of various constituents consisting of alumina, silica, magnesia, and manganese oxide. The main mass of the ore consists of *fowlerite* (a variety of rhodonite), whilst a portion consists of rhodonite and tephroite. The latter is of a yellowish-grey to reddish-brown colour. The fowlerite is of a brown, red, or black colour, with considerable lustre. It occurs occasionally in crystals measuring ¼-inch across. From their external character, the ores appear to have been formed by infiltration.

The Tyrnowa ores have been mined for many years, partly by adit-levels and partly by open workings. They are smelted at the Reschitza Steelworks, where they are found to act as a useful flux for the magnetites and red hæmatites of Dognatschka. The ores have to be carted a considerable distance; but owing to the irregularity of the ground and the comparatively small output, a branch-railway would not be found profitable.

Iron Ores of the Ural.—The following are analyses of iron ores as smelted at the Bjelorezk Ironworks in the Ural:*—

Ore.	Fe_3O_4.	Fe_2O_3.	Mn_2O_3.	MnO.	CaO.	MgO.	Al_2O_3.	S.	P_2O_5.	SiO_2.
Magnetite.	89·66	...	1·92	...	1·51	...	1·23	0·01	0·37	2·24
Limonite.	...	65·68	...	0·17	0·35	0·27	10·79	...	1·27	9·58

They are smelted in a low form of charcoal blast furnace. The pig iron produced contains:—

C.	Mn.	Si.	P.	S.
3·0–4·0	0·2–0·3	0·8–1·0	0·35–0·50	traces.

Iron Ore in New South Wales.—The iron ores of New South Wales consist mainly of magnetite, red hæmatite, limonite, and bog iron ore. The deposits are numerous, and many of them are adjacent to both coal and limestone. This is the case at Mittagong, on the Great Southern Railway, where, according to Mr. C. S. Wilkinson,† about 2,872,000 tons are in sight, the ore containing 48·40 per cen of iron.

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* *Stahl und Eisen*, vol. x. p. 854.

† International Exhibition of Mining and Metallurgy. Official Report on the exhibit of New South Wales.

The following are analyses of some of the ores :—

No.	Fe_2O_3.	FeO.	MnO.	Al_2O_3.	CaO.	MgO.	SiO_2.	H_2O.
1.	72·36	0·00	trace	3·94	1·35	0·86	10·20	11·76
2.	60·48	18·67	0·00	14·22	0·00	0·00	6·50	0·13
3.	79·76	trace	trace	3·62	0·00	0·54	2·72	12·93
4.	82·95	trace	0·08	2·10	0·34	0·00	2·45	11·58
5.	65·20	0·00	0·50	4·50	0·06	0·15	14·45	14·77
6.	79·71	13·04	0·19	2·78	0·39	trace	3·23	6·20

Note.—Phosphorus and sulphur are absent or only present in minute quantit (1.) Brown iron ore from Bathurst County; a lenticular deposit in diorite; ne limestone. (2.) Magnetite from Bathurst County; found in diorite; ore strong magnetic. (3.) Brown iron ore from Newbridge, Great Western Railway; irregul bunch in talchose schist. (4.) Brown iron ore, Myalla station, Blayney-Cowra Ra way; ore occurs in limestone. (5.) Brown iron ore from the Lyndhurst mir Bathurst County; three lodes, two of which are over 35 feet wide. (6.) Magneti from the Broula Range, near Cowra; lode from 60 to 120 feet in width; 90 mil from the Wallerawang coalfield.

In the Wallerawang district, Professor Liversidge states, clay-ban ores are found as well as magnetite and brown iron ore. The cla band ores are interstratified with the coal-measures, and contain abou 30 per cent. of iron. Most of the ores described are very pure.

Iron and Manganese Ore in West Australia.—In the Annu Report of the Government Geologist for 1888–89,[*] it is stated tha West Australia is essentially an iron country, for it is impossible t travel a mile in the parts where the older rocks appear at the surfa without encountering a lode.

The iron ore occurs chiefly in the forms of magnetite and re hæmatite. The lodes are sometimes of immense size, and so abundan is the ore that Mr. Woodward states that it is almost impossible t work with any degree of accuracy with a magnetic compass.

Manganese ore, too, has been found in many places throughout th colony. The ore is of good quality and the lodes are of large siz but none has yet been worked.

Some Ontario Magnetites.—Mr. T. D. Ledyard[†] describes son magnetite deposits found in the counties of Peterboro and Haliburton, and in the more easterly portions of the province of Ontario, Canada. Magnetites only are taken into account, although hæmatites are found in deposits of considerable importance.

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[*] Perth, 1890, p. 25.

[†] *Transactions of the American Institute of Mining Engineers*, vol. xix. (advan proof).

The Belmont iron-mine, the first mine described by the author, is situated about 110 miles east of Toronto. The deposit of rich magnetite contains at least a million tons of ore within 100 feet of the surface. The ore can be mined by the use of compressed air rock-drills at 2s. per ton, no hand-picking being required. Much of the country rock is composed of epidotic diorite.

The following analyses have been made, the first being from surface samples:—

No.	Iron.	Phosphorus.	Sulphur.	Silica.	Manganese.
1.	64·26	trace	0·04	...	...
2.	65·36	0·002	trace	4·50	...
3.	66·29	0·024	trace	3·19	0·42
4.	68·88	0·006	trace	3·18	...
5.	68·85	0·008	trace	1·96	...
6.	69·99	0·012	trace	3·10	...

The Blairton mines, four miles south of the Belmont mine, have been worked to a considerable extent, as much as 400 tons daily having been produced at one time. There are large deposits of magnetite averaging 55 per cent. of iron and 0·035 per cent. of phosphorus, with no titanium.

On the east side the deposit is capped with Silurian limestone, while the west wall is a jaspery quartzite. The strike is west of north. In the wall, quartz and serpentine predominate. This ore is much mixed with rock, necessitating a good deal of sorting, which renders mining expensive. Consequently, this is one of the many iron-mines in Canada which cannot be worked at a profit for export to the United States.

There are several large deposits of magnetite near the Central Ontario Railway in the north part of the county of Hastings. Unfortunately the mines are now lying idle. The ore, like the celebrated magnetite of Cornwall in Pennsylvania, contains sulphur, and requires to be roasted.

The townships of Snowdon, Galway, and Glamorgan, in the county of Haliburton, contain several valuable deposits of iron ore, shown by the following analyses to be very low in phosphorus:—

No.	Iron.	Phosphorus.	Sulphur.	Silica.	Titanium.
1.	61·48	0·010	0·160	...	none
2.	62·00	trace	0·025	1·7	"
3.	62·57	0·025	trace	...	"
4.	63·00	trace	0·025	3·1	"
5.	62·37	0·012	trace	...	"
6.	62·60	0·008	trace	...	"
7.	65·00	0·040	0·020	...	"
8.	70·40	trace	trace	...	"

No. 1 is a fine-grained magnetite from Howland mine, Snowdon. Nos. 2 to 4 are ores from the same township. Nos. 5 to 8 are ores from different parts of Galway township. No. 6 contains 1·27 per cent. of manganese oxide.

The following analyses have been made of magnetic ores from the country tributary to the Kingston and Pembroke Railway:—

No.	Iron.	Phosphorus.	Sulphur.	Silica.	Titanium.
1.	65·33	0·017	...	...	none
2.	66·00	trace	trace	2·14	"
3.	62·00	0·006	trace	4·12	"
4.	60·00	0·009	...	6·31	"
5.	52·00	0·055	0·10	6·53	"
6.	65·07	0·070	0·05	6·66	"
7.	66·34	0·140	trace	1·04	trace

In conclusion, the author describes a number of deposits of magnetic ores containing considerable quantities of titanium. These ores are generally very low in phosphorus, and if some treatment could be found whereby the injurious effects of the titanium could be got rid of they might be used in making steel. The presence of these titaniferous ores in close proximity to deposits in which no trace of titanium can be detected is a fact of much interest hitherto apparently unrecognised in the iron districts of Europe. The author protests against the practice of characterising all Canadian ores as titaniferous. Nothing could be more unfair.

Many of the magnetite deposits in eastern Ontario are rich in iron, and carry, too, very low percentages of phosphorus and sulphur, with no titanium at all. Others are high in sulphur, but still free from other impurities, so that they require roasting only in order to make them available as exceedingly pure 60 per cent. ores. Finally, the rates of wages in these districts generally range from 4s. per day for labourers to 5s. for miners. It is to be hoped, therefore, that something will be done to verify Sir William Logan's prediction that Canada will eventually become one of the greatest iron-producing countries in the world.

Iron Ore in Colorado.—Mr. T. Tonge[*] discusses the development of the iron industry in Colorado, with special reference to Gunnison County. Within 30 miles of the town of Gunnison, large deposits of iron ore are found, and also the necessary coking coal and pure limestone for flux. The ores lie in several parallel beds, of which only one has been extensively explored. This bed contains magnetic oxide with 66 or more per cent. of iron, and in some places reaches a thickness of 70 feet. The anthracite contains 82 per cent. of fixed carbon, and coking coals show 67 per cent. The former coal lies in a bed from 5 to 5½ feet thick, the latter from 4½ to 5 feet. The cost of production of Bessemer pig iron is calculated at about £2, 5s. per ton. Lower grade ores can easily be produced for the manufacture of different qualities of iron. Large bodies of manganese ores are found in the vicinity.

Iron Ore from South-West Virginia.—Mr. E. C. Pechin[†] states that iron ore from Carroll County has the following percentage composition :—

Iron	45–54
Silica	4–10
Phosphorus	0·02–0·14
Sulphur	0·26–0·70
Copper	0·27–0·80

It is a readily reducible porous hydrated ore, and exists in large quantity.

Tennessee Iron Ores.—The following partial analyses show the composition of the iron ores found in the Cranberry district: [‡]—

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[*] Letter to the *Denver Republican*, August 10, through the *Iron and Coal Trades Review*, vol. xli. p. 234.

[†] *Roanoke Times*, through *Iron Age*, vol. xlv. p. 809.

[‡] *Iron Age*, vol. xlv. p. 897.

No.	Origin.	Iron.	Phosphorus.	Titanium.
1.	**Cranberry mines**	58·35	0·0071	0·007
2.	„ „	40·79	0·0767	none
3.	„ „	41·13	0·0319	0·012
4.	„ „	50·77	0·0087	0·013
5.	**Davis Tract**	45·97	0·045	none
6.	Poplar opening	47·88	0·017	„
7.	East Tenn. M. & I. Co. . . .	54·63	0·032	trace
8.	„ „ „	63·63	0·036	none
9.	Fork Ridge	55·12	trace	„
10.	Wilcox	57·74	0·017	„
11.	East Tennessee	56·14	trace	„
12.	„ „	66·39	0·0067	„

South American Iron Ores.—In the valley of the Orinoco river South America, iron-ore mines were opened about two years ago, anc the shipments to the United States since that time have amounted tc about 2000 tons. It is stated that a lack of mining and shipping facilities has prevented larger shipments. The ore is of a large-grainec specular character, and rich in iron. Analyses show that it contains from 65 to 69 per cent. of iron; with silica, ranging from 1·76 to 8·58 per cent.; lime, from 0·12 to 0·75 per cent.; sulphur, from a trace to 0·181 per cent.; and phosphorus, from a trace to 0·045 per cent. The majority of the samples analysed show the percentage of phosphorus to have been less than 0·03 per cent. The ore is readily smelted, and is practically self-fluxing.

Concerning the extent and character of the deposit, Mr. S. Norton states that the ore occurs upon a spur of the Imataca Mountains, 54 miles from the mouth of the Orinoco river, and is reached by vessels drawing 18 feet of water. The point at which the ore is at present being mined is two miles from the Orinoco river, a small arm of the river passing round and forming an island called Corisimo. This branch of the Orinoco has an average width of 350 feet, and is 30 feet deep, large vessels being able to come within 50 feet of the shore at any point, and at some places still nearer. The ore is 1600 feet from and 200 feet above the river, both river and mountain running in the same general direction, namely, west to east. Boulders of iron ore weighing from 100 lbs. to 100 tons cover the tops of the hills for a distance of 3000 feet in length and 100 feet in width, there being in sight from 150,000 to 200,000 tons of Bessemer ore. The true vein shows an average thickness of 12 feet, and samples taken at widely separated points show an unchanging character. The boulders of iron ore are to be found at points 6, 32, and 35 miles to the westward. A large outcrop of ore is also to be seen on Corisimo Island. Being so near the water, the ore can be loaded direct into ships at a minimum cost by means of an automatic inclined plane, the loaded trucks pulling up the empty ones.[*]

Iron Ore in Chili.—In reporting on the iron-ore deposits of Chili with a view to inquire into the possibility of erecting blast-furnaces, C. Vattier[†] gives the following analyses :—

	Fe_2O_3.	Mn_2O_3.	SiO_2.	CaO.	Loss on Ignition.
I. . . .	60·0	25·0	6–8	...	...
II. . . .	5·80	40·70	10·10	22·25	20·55
III. . . .	5·44	51·00	...	...	17·60
IV. . . .	5·44	73·00	16·14	...	4·95
V. . . .	1·33	52·00	3·83	...	13·10

I. Ore from a vein 8 yards in thickness at the Chamonate Mountain, near Copiapo. II. Manganese ore, containing 29·3 per cent. of manganese, from Quebrada de Cañas, Elqui. III. Manganese ore from the Alta mine, Elqui, with 36·72 per cent. of manganese. IV. and V. are from other deposits in the same locality.

Limestone suitable for flux occurs abundantly in Chili, and the author gives a number of analyses of limestones from different localities.

Composition of Manganese Ores.—A. Gorgeu[‡] has analysed three samples of psilomelane from Romanèche, from Thuringia, and from Lorca (Spain).

The higher oxides of manganese are not present in the form of dioxide, but in that of manganous manganites, such as $MnO, 6MnO_2$, and $MnO, 8MnO_2$. The basic oxides are variable; manganous and barium oxides occurring in the ore from Romanèche, and manganous, barium, and sodium oxides in that from Lorca. All the psilomelanes are hydrated, and the most basic have the composition $RO, 3MnO_2$.

Wads from Romanèche, Giessen, and other localities were also examined. Some varieties were found to be crystalline, a fact not hitherto observed. Like the psilomelanes, they are manganites with variable quantities of base, their composition varying between $MnO, 7MnO_2$, and $MnO, 10MnO_2$.

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[*] *Bulletin of the American Iron and Steel Association*, September 17, 1890.

[†] *L'Avenir de la Métallurgie du Fer au Chili*, Paris, 1890.

[‡] *Comptes Rendus de l'Académie des Sciences*, vol. cx. pp. 247–249.

The energy of the acidic function of the manganese dioxide is shown by the fact, that when finely powdered psilomelane or wad is boiled with nitric acid diluted with four volumes of water, but a very small proportion of the basic oxides is dissolved even in the case of the varieties that are richest in barium.

Manganese Ore in the Caucasus.—Deposits of manganese ore occur on both banks of the Quirila in the vicinity of Tschiatura. The ore is met with in six to eleven beds intercalated with beds of Tertiary sandstone. The whole series forms a bed of 5 to 10 feet in thickness. The ore averages 55 per cent. of manganese, and contains 1·69 to 6·67 per cent. of silica and a fairly large proportion of phosphorus—as much as 0·15 to 0·20 per cent.

At the present time manganese ore is exported exclusively from Poti, the exports having increased from 9380 tons in 1882 to 50,727 tons in 1888. It is expected that in 1890 the exports will be double the latter amount. Manganese ore is sold at the mine for 6s. 3d. to 7s. 6d. per ton. The transport to Poti costs £2, 3s. per ton. The manganese industry is distributed amongst a great number (86 in the year 1888) of small mines.*

The Formation of Chrome Iron Ore.—According to Meunier,† the occurrence of chrome iron ore in serpentine may be compared with the experiment of heating the sub-chlorides of iron and chromium in a current of hydrogen. In this way chrome iron is produced, which by the after-action of steam is converted into chrome iron ore.

A Natural Nickel-Iron Alloy.—At the Conversazione of the Royal Society, held on June 18, Professor J. W. Judd exhibited specimens of a remarkable nickel-iron alloy (awaruite), of terrestrial origin, from New Zealand, and of the minerals and rocks with which it is associated, sent by Professor G. H. F. Ulrich, of the Dunedin University. This curious mineral, consisting of 2Ni + Fe, was analysed and named by Mr. W. Skey in 1885, having been detected by him in specimens of sands obtained from streams in the south-western part of the South Island of New Zealand. Professor Ulrich has since been able to show that the grains of this alloy are found over a considerable area, disseminated in peridotite and serpentine rocks, which rocks are intrusive in the metamorphic schists of the district, and form the Red Hill and Olivine Ranges. The substance which awaruite most closely resembles is the Oktibbehite nickel-iron meteorite; and the occurrence of this remarkable alloy in terrestrial rocks is comparable to the presence of nickel-iron alloys in the basalts of Ovifak and other localities in Greenland.

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* *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 401.

† *Comptes Rendus de l'Académie des Sciences*, vol. cx. p. 424.

A full account of the geology of the district and of the mode of occurrence of the awaruite is given by Professor Ulrich * in a paper read before the Geological Society.

The composition of this alloy is as follows:—

Nickel.	Cobalt.	Iron.	Sulphur.	Silica.
67·63	0·70	31·02	0·22	0·43

Its specific gravity is 8·1, and its hardness about 5.

Recent Researches on Meteorites.—In a paper read before the Austrian Society of Engineers and Architects, A. Brezina † described meteoric iron, and discussed the difference which it shows when compared with ordinary iron. Meteoric iron, the author observes, usually contains from 89 to 95 per cent. of iron, and 4 to 10 per cent. of nickel; though the percentage of this latter element occasionally reaches from 10 to 15. Only one instance is known in which the percentage of nickel present exceeds that of the iron—the Oktibbeha meteorite, with 60 per cent. of nickel and 38 of iron. Cobalt, sulphur, phosphorus, carbon, and chromium are never present in any large quantity.

A meteorite when newly fallen is always found to be covered with a thin film of magnetite. The various meteorites closely resemble one another in their structure. All meteorites show the Widmannstatt figures on etching, but no mineral has been found to possess this property.

Meteorites, according to their structure, may be divided into three classes: (1) octahedral, (2) hexahedral, and (3) the massive variety, forming an intermediary between the other classes and ordinary manufactured iron. Photographic reproductions are given showing the structural arrangement of these three main types; and the method of preparing sections is also described.

A meteorite, which formed one of a meteoric shower in Iowa on

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* *Quarterly Journal of the Geological Society*, vol. xlvi. pp. 619–632, with geological map and plate.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 355.

May 2, 1890, has been analysed by Mr. J. Torrey and Mr. E. H. Barbour,[*] with the following results:—

Silica.	Ferric oxide.	Alumina.	Lime.	Magnesia.	Total.
47·03	29·43	2·94	17·58	2·96	99·94

Mr. G. F. Kunz describes material from the same fall as a porous stone with specific gravity 3·638. Troilite and metallic iron in grains are present, whilst a soft black material contained in the stone is supposed to be graphite. A felspar was observed, and enstatite was also present.

Mr. L. G. Eakins[†] describes a specimen of meteoric iron from North Carolina. The iron described was found in 1880 on a farm near Ellenborough, Rutherford County, and weighed originally 4·8 lbs. In shape it was, roughly, two globular ends with a connecting bar. The iron is very tough and highly crystalline. Small irregular patches of troilite are visible, and schreibersite also seems to be present. Analysis of the iron yielded:—

Fe.	Ni.	Co.	Cu.	P.	S.	Si.	Total.
88·05	10·37	0·68	0·04	0·21	0·08	0·02	99·45

Analysis of Lake Superior Iron Ores.—Geo. W. Goetz, M.E., Milwaukee, Wis., read at the New York meeting of the American Institute of Mining Engineers, September 1890, a paper on this subject.

The following tables show the analyses of ores from nearly all of the mines which produced over 10,000 tons of ore each during the season of 1890.

There are many small mines now in the course of development, some of which may become large producers. Many of the mines produce several different grades of ore, but the analyses given in the tables are fair averages of ore such as the respective mines can deliver.

Most of these analyses were obtained from the agents of the respective ores, and are averages of the season of 1889.

It can be stated positively that 75 per cent. of all the iron ores of the Lake Superior district will average over 60 per cent. of metallic iron.

During the past thirty-four years this region has produced about 48,138,421 tons of ore, the different districts contributing about as follows:—

Marquette district	29,754,057 tons.
Menominee ,,	10,415,859 ,,
Gogebic ,,	5,622,194 ,,
Vermilion ,,	2,342,991 ,,
Miscellaneous	2,320 ,,

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[*] *Science* (May 9); *Nature*, vol. xlii. p. 136.

[†] *American Journal of Science*, vol. xxxix. pp. 395–396.

In the year 1889 the production of all the districts was nearly 7,300,000 tons. The production of the entire regions for the season of 1890 may exceed 9,000,000 tons. This large amount of ore is shipped to the lower lake ports, from either Escanaba, Marquette, Two Harbours, or Gladstone.

I. ARQUETTE DISTRICT.

Name of Ore.	Iron.	Phosphorus.	Silica.	Manganese	Alumina.	Magnesia.	Lime.	Sulphur.
	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.
American	65·00	0·045	4·50	...	...	...	...	...
Angeline, Hard	66·50	0·009	...	...	...	...	...	...
,, Hematite	66·38	0·032	...	...	...	...	...	...
Barnum	65·00	0·098	4·70	0·20	0·20	0·20	0·35	trace
Buffalo	62·33	0·120	6·80	0·37	1·61	0·06	...	...
Cambria	60·00	0·064	7·26	0·37	3·81	0·33	0·62	0·042
Champion, No. 1	67·00	0·040	3·00	...	...	...	...	...
Cleveland, No. 1	65·60	0·104	3·06	0·21	0·99	0·18	0·37	0·037
,, Hematite	60·00	0·050	6·74	0·63	2·35	0·12	0·12	0·011
Cliff Shaft	62·70	0·109	3·45	0·52	1·55	1·15	1·61	0·025
Comrade	60·50	0·100	...	...	...	...	...	...
Detroit	58·60	0·056	8·00	...	...	...	...	...
East New York	60·10	0·055	11·64	0·41	1·11	0·31	0·12	0·029
Humboldt	65·00	0·120	5·00	0·12	0·72	0·26	0·64	0·020
Imperial	57·50	0·280	5·30	0·03	1·71	0·41	1·16	0·045
Jackson	62·00	0·090	...	...	...	...	...	...
Lake Superior, No. 1 A	64·00	0·110	...	...	...	...	...	...
,, ,, Slate	66·00	0·080	3·00	0·03	1·22	0·12	0·48	0·045
Lillie	59·00	0·084	8·69	...	...	...	...	...
Lucy	53·50	0·045	12·05	4·25	...	...	...	...
Michigamme	65·50	0·114	4·57	0·01	0·51	0·11	0·07	0·030
,, No. 1	62·00	0·055	7·00	0·60	0·80	0·30	1·35	0·030
Milwaukee	62·05	0·105	4·32	0·45	0·60	0·90	1·10	0·080
Mitchell	60·95	0·131	6·85	0·62	1·35	0·30	0·42	0·020
Negaunee	60·00	...	...	...	...	...	...	...
Prince of Wales	62·56	0·106	5·51	0·37	1·70	0·17	0·59	0·053
Prout	53·02	0·041	17·65	...	...	...	...	...
Queen	62·60	0·112	4·65	0·41	1·11	0·31	0·12	0·029
Republic, Magnetic	69·77	0·051	1·78	...	...	...	...	...
,, Specular	67·50	0·043	3·01	0·04	0·85	0·07	0·41	0·012
Salisbury Bess	62·00	0·045	4·00	0·22	0·50	0·60	1·00	0·012
Sharon	61·00	0·090	8·00	0·12	0·72	0·26	0·84	0·012
Sheffield	61·00	0·015	...	...	...	...	...	...
South Buffalo	63·80	0·100	4·10	0·31	1·49	0·34	0·82	0·049
Volunteer	60·10	0·070	...	...	...	...	...	...
Winthrop	63·40	0·109	5·37	0·85	0·81	0·11	0·24	0·028

II. MENOMINEE DISTRICT.

Name of Ore.	Iron.	Phosphorus.	Silica.	Manganese	Alumina.	Magnesia.	Lime.	Sulphur.
Aragon	65·20	0·038	4·68	0·02	0·33	0·01	0·36	0·034
Armenia	60·80	0·188	8·69	0·11	1·33	0·39	0·66	0·022
Chapin	62·13	0·068	4·20	0·26	1·08	2·71	0·81	0·001
Commonwealth	57·70	...	...	...	...	...	...	...
Corbett	58·20	0·675	4·37	0·31	3·10	0·62	0·78	0·041
Crescent	64·55	0·044	3·35	0·15	0·67	1·64	0·50	...
Cyclops	61·00	...	...	...	...	...	...	...

II. MENOMINEE DISTRICT—*Continued.*

Name of Ore.	Iron.	Phosphorus.	Silica.	Manganese	Alumina.	Magnesia.	Lime.	Sulphur.
	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.
Dunn	60·60	0·344	4·81	0·22	2·98	0·81	0·97	0·036
Eagle	55·20	0·547	5·03	0·02	...	0·81	5·91	0·061
Florence	60·50	0·257	4·05	0·22	0·81	0·64	1·18	0·041
Great Western	...	...	...	...	...	...	...	...
Iron River	59·80	0·356	5·29	0·37	3·41	0·37	0·69	0·028
Ludington	64·59	0·070	...	...	...	...	...	...
Manganate	54·00	0·642	6·00	3·50	...	...	...	...
Mansfield	63·40	0·025	3·56	0·55	2·28	8·00	4·00	0·033
Mastodon	58·36	...	...	...	...	...	...	...
Millie	64·06	0·027	3·00	0·08	1·30	0·95	1·10	0·035
Norway	58·00	0·120	12·00	...	...	...	...	...
Paint River	56·40	0·502	3·48	0·37	6·12	0·72	5·58	0·068
Pewabic	65·00	0·010	...	...	...	...	...	...
Rex	55·78	0·080	6·85	...	1·67	...	...	...
Shafer	59·00	...	...	...	...	...	...	...
Vulcan	62·00	...	...	...	...	...	...	...
Youngstown	52·18	0·642	6·00	3·50	...	...	...	...

III. GOGEBIC DISTRICT.

Name of Ore.	Iron.	Phosphorus.	Silica.	Manganese	Alumina.	Magnesia.	Lime.	Sulphur.
Anvil	61·54	0·053	...	...	...	...	...	...
Ashland	63·82	0·038	...	...	...	...	...	...
Aurora	63·36	0·034	4·00	0·03	1·98	0·12	0·04	0·033
Brotherton	62·50	0·037	6·13	0·49	2·98	0·39	0·16	0·070
Cary	58·84	0·062	5·20	...	...	3·66	...	...
Eureka	62·00	0·076	6·64	0·48	3·69	0·16	0·15	0·015
Germania	59·19	0·058	...	...	...	...	...	...
Hennepin	65·45	0·048	3·53	0·02	0·31	0·02	0·02	0·022
Iron Belt	62·75	0·042	6·33	...	2·44	...	...	0·037
Ironton	60·55	0·058	...	...	...	...	...	...
Montreal	64·22	0·053	...	...	...	...	...	...
Mount Hope	63·32	0·029	...	...	...	...	...	...
Norrie	63·72	0·043	3·40	...	...	...	...	...
Pabst	62·34	0·037	4·50	...	...	...	...	...
Palms	62·43	0·049	...	...	...	...	...	...
Ruby	62·50	0·045	4·20	0·49	...	0·16	0·45	...
Section 33, North	64·82	0·045	...	...	...	...	...	...
Sunday Lake	62·00	0·036	...	...	...	...	...	...
Trezona	62·55	0·061	4·44	0·02	0·97	0·03	0·02	0·031
West Cary	54·95	0·054	5·35	7·41	...	...	...	...
Windsor	62·00	0·051	6·30	0·81	3·45	0·31	0·40	0·025

IV. VERMILION DISTRICT.

Name of Ore.	Iron.	Phosphorus.	Silica.	Manganese	Alumina.	Magnesia.	Lime.	Sulphur.
Braddock	65·17	0·052	4·50	0·13	0·48	0·16	0·56	0·020
Chandler	64·15	0·044	4·30	0·14	2·25	0·19	0·25	0·040
Long Lake	60·20	0·053	7·00	0·54	2·75	0·19	0·25	0·047
Minnesota	67·54	0·051	1·97	0·15	0·40	0·14	0·53	0·020
Nipigon	63·01	0·053	6·75	0·14	0·65	0·20	0·60	trace
Red Lake	62·86	0·099	6·95	trace	0·65	0·20	0·60	,,
Soudan	65·77	0·102	4·25	0·16	0·38	0·17	0·56	0·020
Vermilion	67·31	0·091	2·15	0·15	0·35	0·15	0·58	0·020

II.—*IRON-ORE MINING.*

Poetsch Shaft-Sinking Process.—The Poetsch process [*] of sinking shafts by freezing has recently been successfully applied in a shaft of the Georgenberg iron-mine near Tarnowitz. The iron ore is covered by a bed of quicksand of Tertiary age. The shaft was completed on October 16, 1890.[†]

Pumping-Engine at the Rhymney Mines.—A large pumping-engine for draining the Rhymney iron-mines in South Wales is illustrated in the *Engineer.*[‡] The cylinders are 45 and 72 inches in diameter, and the stroke is 10 feet. The depth of the shaft is 720 feet, and the water is raised in one lift by two plunger-pumps, each 20 inches in diameter. The rising main is 20 inches in diameter.

Exploration for Iron Ore with the Magnetic Needle.—H. Sjögren [§] gives some interesting instances of successful magnetic surveys. From a shaft in the Persberg iron ore region in Sweden a level was driven for a distance of about 360 feet at a depth of 600 feet, and abandoned, as the ordinary mining compass failed to indicate the presence of ore. Early in 1888, however, a magnetic survey was made with Tiberg's instrument, and this clearly showed that there must be an ore-pole 50 to 55 feet to the north of a point in the cross-cut. Mining was resumed, and 50 feet driven, but nothing was found. A fresh magnetic survey showed, however, that the level was a little to the side of the ore-pole, which must be situated in the immediate vicinity. Two days afterwards ore was struck, and the ore-body has been opened for a length of 50 feet and a width of 20 feet without the limits being reached.

At another mine a magnetic survey was made along several lines, preparatory to putting down an exploratory bore-hole at the deepest point. All the arrows indicating magnetic force converged to one point at which the bore-hole was put down. At a depth of 33 feet a body of ore measuring 60 feet across was encountered.

The method is cheap and expeditious, as a level 400 to 500 feet in length can be magnetically surveyed in one day. The same length of time is required for the calculations and plotting. A survey of this kind covers 70 to 100 feet on either side of the level. In an ore-field containing very small scattered bodies of ore or impregnations the method does not answer so well.

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[*] *Journal of the Iron and Steel Institute*, 1890, No. I. p. 207.

[†] *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 409.

[‡] Vol. lxx. p. 230 and plate.

[§] *Wärmländska Annaler; Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 318. Compare paper on this subject by B. H. Brough, *Journal of the Iron and Steel Institute*, 1887, No. I. p. 289.

III.—*MECHANICAL PREPARATION.*

Iron Ore Concentration.—The Thomas ore-washer for clay-bearing iron ores is illustrated in the *Engineering and Mining Journal.*[*] It is a form of trough-washer with two revolving shafts furnished with helically arranged teeth. The box is usually 25 feet long, 5 feet wide, and 2 feet deep. A rotary screen may be used at the lower end to rewash the tailings when the washer is inclined so as to run a considerable quantity of small ore through with them. The revolving shafts are preferably geared together and driven by a pinion on a countershaft which is driven by a belt from the engine. For a washer of the dimensions given above, 35 to 40 gallons of water per minute are required, and 12 to 15 horse-power. The capacity is 50 to 70 tons daily.

The M'Lanahan Ore-Washer.—The use of the ore-washer has of late developed to a larger extent in Virginia, Georgia, Alabama, and Tennessee than elsewhere, but the forms principally employed are either the shaft or the cone washers. The shaft-washers are single or double, the latter being preferred, and consist of one or two logs of wood iron-bound and fitted with blades; these logs revolve in a trough in which the ore and water are placed, the revolving blades cutting up the clay lumps and forcing the ore up the inclined bottom of the trough, the water carrying away the clay to suitable settling tanks. In the M'Lanahan machine, the ore as brought from the workings is discharged from mine trucks on a screen through which all but the lumps pass into the trough. These lumps are fed into a crusher, and from this also drop into the trough, unless it is desired to ship them without washing. As, however, much clay adheres to or is enclosed in the nodules of brown hæmatite ore, the washing of the broken lumps is advisable. As the blades cut or push the ore forward in the trough, it is met by a stream of water which washes away the clay, the ore passing out at the upper end of the trough into a revolving screen, where it receives a final rinsing with water. In some instances the fine ore passing through 1-inch round holes is then treated by jigs.[*]

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[*] Vol. l. p. 11.

The Magnetisation of Iron Ore.—Mr. C. Jones[†] points out that the anhydrous oxides of iron in general are magnetic. Of all the hydrous oxides of iron, however, not one is magnetic. Brown hæmatite or limonite, as well as the sub-varieties of hydrous oxides, are non-magnetic, and have no effect on the magnetic needle. Since the discovery of rich red hæmatite ore in the United States, hundreds of productive brown hæmatite mines have been abandoned, and there are still numerous undeveloped beds too poor to be profitably mined. A perfect method of concentrating this ore, which rarely contains more than 37 per cent. of iron, would mean a revival of this source of supply.

On rapidly drying a small sample of limonite over a Bunsen flame, the author observed that the smaller particles were magnetised. He therefore experimented on a more practical scale with different ores, and found that all the ore particles were so strongly affected as to permit their complete separation by means of a magnet. The mode of conducting the experiment was as follows:—The ore is placed in a convenient receptacle and merely roasted by the usual process, using either solid or gaseous fuel. It is undesirable to use much heat, since at a temperature of cherry-red magnetisation is fully imparted. The ore is drawn as fast as it reaches this temperature, and is at once ready for magnetic separation.

The commercial success of treating ores in this way depends on the three items: cost of washed ore; cost of roasting; and cost of concentration. The first may be considered to range from 3s. to 6s. per ton, according to locality. The second item, according to the books of a large company exclusively engaged in roasting carbonate ores, would amount to 8d. for roasting and 3½d. for handling, or to a total of 11½d. per ton of ore treated. The third item would be 1d. per ton for concentrating and 1s. for royalty. The cost of concentrating an ore containing 33·55 per cent. of iron would be:—

Cost of 1½ ton of ore	9s.	0d.
Cost of roasting	1s.	6d.
Cost of concentration and royalty	1s.	1d.
Total . .	11s.	7d.

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[*] *Iron Age*, vol. xlv. p. 631.

[†] *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

The concentrates yield 48·63 per cent., and the tailings 2·56, so that 70 per cent. of ore is recovered as concentrates. At a yield of 48 per cent., the above total represents 24s. to the ton of iron.

The phenomenon of magnetisation seems to be connected with the expulsion of the combined water, and the author is of opinion that it is largely dependent on its physical separation from the ore. During the process some of the oxides glow strongly. The raw oxide, when heated to redness in a closed glass tube, gives off a small amount of carbonic anhydride with the water, but it is only feebly magnetic. There is no apparent evidence that ferrous oxide is produced by decomposition of the water. The only statement possible is that the hydrated oxides of iron become magnetised at a red heat in contact with carbon or carbonic anhydride.

Magnetic Concentration at the Michigamme Mine.—Mr. J. C. Fowle * describes the successful employment of the Wenström magnetic separator † at the Michigamme iron mine, Lake Superior. In the first place, he erected a small crude mill with several sizes of screens so as to size the material and treat the different sizes by themselves on the separator, a machine with 15-inch face of drum. From this mill 11,000 tons of concentrates were shipped in 1889. A portion of this, produced from crude 50 per cent. ore, contained 65 per cent. of iron, whilst the remainder, produced from crude 53 per cent. ore, carried 60 per cent. of iron.

Experience shows that the fine powdered ore and the ore going through a ¼-inch screen should never be allowed to fall directly on the separator, but should be carried near it by a belt on an inclined plane and attracted to the drum by electro-magnetic force. It is almost impossible to feed this fine ore directly on to a separator in a sheet sufficiently thin to permit a satisfactory separation, because ore and rock overlying one another are bound together in the drum; but by feeding the fine ore by a belt up to the separator the mass of material is agitated, and the ore flies to the drum and the rock falls or remains on the belt. The greater the electric current which is carried on the separator, and the farther away from the separator the crude ore is when it enters the magnetic field, the higher will be the percentage of iron in the concentrates and the lower in the tailings. For instance, crude ore, containing 52 per cent. of iron and 0·224 of phosphorus, when treated directly on the separator, gave concentrates in one case containing 58 per cent. of iron and 0·215 of phosphorus, and in another case 60 per cent. of iron and 0·180 of phosphorus; whilst the same ore, treated by a belt-feed, not in contact with the separator, gave concentrates containing 67·07 per cent. of iron and 0·160 of phosphorus.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

† *Journal of the Iron and Steel Institute*, 1889, No. I., p. 244.

All the underground skips that carry lean rock or "waste" are tipped at the shaft-houses upon long, flat screens made of round bar-iron, with bars 1¼ inch apart. The material passing these screens ranges in size from powder up to pieces 1¼ inch thick by 3 inches wide, some of which weigh as much as 4 lbs. each. These screenings and the lean lump-ore are conveyed to the concentrating mill over gravity roads.

On the east and west sides of the mill are skip-roads, by which all the mixed ore from old waste heaps is hoisted up into the bins over the crushers. These skip-roads run under the railway, space being left so as to permit of the interposition of a bin holding a waggon-load of ore—8 tons. By this arrangement the refuse from all parts of the property, when loaded into waggons, can be shunted at small cost to these bins and tipped into skips.

The mill is 50 by 60 feet, and has cost £3200. The machinery includes one 60-horse-power engine, two dynamos run by one engine, one boiler, two drums for hoisting skips, one 18 by 24-inch crusher, one 9 by 15-inch crusher, one set of 36-inch rolls, one 36-inch Buchanan separator,* one 15-inch Wenström separator, one shaking-screen, and a swing-screen.

All the machinery works automatically, only one man being required to attend to it. Up to September in this season (1890) from this mill 8000 tons of concentrates have been shipped, and the mill is now daily concentrating 180 to 200 tons, at a cost, including crushing, hoisting material into bins, separating ore and loading it into waggons, of 9d. per ton. On some days the concentrates at this mill cost only 5d. a ton, delivered in the railway trucks, including all the above-mentioned items of cost.

The quality of the concentrates is regulated entirely by the electric current and the sizing of the material. Most of the concentrates will pass a ¾-inch screen, though some, which are produced from the mine-screenings, are of larger size. These mine-screenings go directly to the separator as 52 per cent. ore, and leave it as 65 per cent. ore. Considering their wide range of size, this may be regarded as very fair work. The waste rock resulting from the separation of the screenings amounts to from 10 to 15 per cent. of the total quantity of crude ore. Whenever this waste product is considered sufficiently rich to warrant further treatment, it is crushed and sized with the lump-ore, and passes through a second separation.

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* *Journal of the Iron and Steel Institute*, 1889, No. I. p. 243.

The proportion of waste made from crushed ore is much larger than from the mine-screenings. This only indicates that the lean lump-ore is of poorer grade than the more friable material which breaks into small pieces in mining and forms the screenings. The amount of tailings varies, of course, with the kind of material being crushed. It fluctuates between 30 and 50 per cent. for most of the separated ore, which runs in size from ¼ to ¾ inch. The tailings contain from 21 to 24 per cent. of iron.

Ore-Dressing by Electricity at the Tilly Foster Mine.—According to Mr. F. H. M'Dowell,* the electric-magnetic separator of Mr. G. Conkling, described by Mr. Birkinbine,† has been in successful operation at the Tilly Foster mine for a considerable period, under the disadvantages which seem to be the inevitable attendants of pioneer enterprises in new technical fields.

The local difficulties in the way of this experiment at the Tilly Foster mine were considerable. Only about two-thirds of the waste-heap, resulting from the assorting of previous years, is ore; and this varies in contents of iron from 20 to 28 per cent. The remainder is rock, some showing particles of adhering mineral, some being entirely barren. The expense of overhauling the heap and removing this rock is by no means the least of the numerous items which must be charged against the concentration. Associated with the lean ore are hornblende and other minerals, carrying iron in the non-magnetic state, which must necessarily be washed away with the tailings. The site for the waste-heap was originally selected without reference to future treatment, and the material now can only be handled by means of a locomotive. The mineral is so widely and finely disseminated through the ore that it has been necessary to resort to fine crushing. This, necessitating the use of water, increases the proportion of slimes, which mechanically carry off small particles of mineral. Finally, the lean character of the ore calls for the handling and conveying from the mill of a large bulk of tailings. The process includes crushing the ore by a Blake stone-breaker on the waste-heap; removing it in train-loads to the bins in the mill; passing it under two Ball stamps, provided with screens of $\frac{1}{16}$-inch mesh; raising it to the Conkling electrical separating belts; and delivering the concentrates to the waggons and the tailings to the settling-reservoirs.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

† *Ibid.*, vol. xvii. p. 739.

During the six months ending July 31, 1890 (the work of January being omitted from the calculation), there were treated 18,058 tons of lean ore, an average of 3009 tons per month. The concentrates produced amounted to 6236 tons, an average of 1039 tons per month. There were required, therefore, 2·89 tons of crude ore to produce 1 ton of concentrates. The average cost of treatment, including preparing the ore and getting it to mill and disposing of the tailings (which items make up one-half of the charge for labour), was 9s. per ton of concentrates. The actual expenses in the mill have averaged 6s. 6d. per ton of concentrates. These figures will be materially reduced when the supply of waste ore from the waste-heap has been exhausted and a higher grade of lean ore is sent directly from the mine to the mill.

The figures for August 1890 show 1391 tons concentrates from 3508 tons of crude ore, or 1 : 2·52. The cost per ton of concentrates was 7s. 6d., as compared with 9s. 7d. in July. The reduction of cost is due to the increased output of the mill in concentrates, a larger amount of crude ore having been treated, and also a larger yield obtained per ton of crude ore.

The following practical conclusions are suggested by these results:—

1. Unless the situation and other conditions are exceptionally favourable, it will not pay to erect works to treat the material of waste-heaps carrying less than 25 per cent. of iron.

2. Where the lean ore is mined in connection with shipping ore there must be a corresponding increase in the percentage of iron to offset the mining and royalty charges.

3. Where no shipping ore is produced, there must be a still further increase in the percentage of iron to warrant the erection of hoisting, pumping, and dressing works.

Magnetic Separator for Iron Ore.—Mr. C. M. Ball* describes the Ball and Norton "Monarch" magnetic separator. The iron ore is fed into a hopper, and falls on to the surface of a hollow non-magnetic drum revolving about one hundred times per minute.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

Within this drum is placed an electro-magnet with a number of arms which only occupy about a third of the periphery of the drum. Th particles of ore are held against the drum and turned about as they pass the successive arms of the magnet, each alternate arm bein oppositely polarised. As the particles pass beyond the range of th magnet, they are thrown off by centrifugal action, and come into contac with a second similar drum, which revolves at a slightly lower rate o speed. The separation of the gangue is facilitated by the turning o the particles on the drums, and by an air-blast. The second drun throws the concentrates into the last of three hoppers, while th gangue falls into the first and second hoppers.

Provision is made for the circulation of air in the casing. Two form of the separator are illustrated. The first has the drums on a level, an is adapted for fine ore; the second has the last drum at a lower leve and is intended for cobbing ore the size of chesnut coal. A machin with drums 24 inches in diameter, and 24 inches on the face, will dea with 15 to 20 tons per hour of ore granulated to pass a screen of 16 t 20 meshes to the inch. The power required is 1 to 1½ horse-powe in electricity for each drum, and ¼ to ¾ horse-power to drive th machine. The following table gives some of the results obtaine with these machines:—

Mine.	Crude Ore.		Concentrates.				Tailings.		
	Fe.	P.	Fe.	P.	SiO_2	S.	Fe.	P.	Per Ce Orig Weig
Benson Mines, Little River	45·48	0·158	61·40	0·042	...	...	5·60	1·25	29·
	41·24	0·25	63·31	0·042	...	...	5·47	...	..
	40·51	0·19	63·68	0·045	...	...	3·87	...	..
	43·02	0·19	62·10	0·022	...	...	...	...	..
Port Henry, New Bed	47·70	0·025	70·40	0·011	...	...	4·40	0·061	38·
,, ,, Old Bed, 21	58·30	2·18	71·10	0·110	...	...	8·70	10·61	19·
Flagler, Vermont, ore	23·74	0·408	64·87	0·084	...	...	4·13	0·465	68·
Chateaugay, New York, 16-mesh	44·56	...	66·69	...	...	...	1·26	...	44·
4-mesh	33·99	...	59·58	...	...	...	10·64	...	52·
8-mesh	31·23	...	62·11	...	...	...	7·32	...	61·
16-mesh	36·23	...	56·98	...	...	...	8·12	...	59·
16-mesh	19·60	...	60·48	...	...	...	8·96	...	84·
Tilly Foster	50·25	...	61·12	...	...	...	7·88	...	20·
Beach Glen, N. J., ore	50·81	0·042	64·88	0·020	...	...	7·06	0·082	25·
Benson Mines, Little River, 16-mesh	...	...	68·45	0·022	4·78	...	...	...	..
16-mesh	...	...	67·49	0·016	5·64	0·32	...	...	..
20-mesh	...	...	68·62	0·0106	4·18	0·34	...	...	..
20-mesh	...	...	67·81	0·013	5·19	0·27	3·39	...	..
Chateaugay tailings	11·80	...	68·36	0·008	4·31	...	4·33	...	89
Port Henry, New Bed	...	...	70·90	0·0089	1·48	...	...	...	38
,, ,, Old Bed, 21	58·70	2·25	71·10	0·037	...	...	...	...	20
Croton, New York, ore	42·99	0·153	69·86	0·021	...	0·04	7·95	...	47

IV.—*METALLURGICAL TREATMENT.*

Calcination of Spathic Iron Ore.—The calcination of spathic iron ores, especially when conducted with a view to concentration of the proportion of metal in the ores, consists in the removal of the carbonic anhydride from the carbonates present, and in the formation of Fe_3O_4 and Mn_3O_4. Hitherto it has not been possible, in consequence of the large amount of material treated and the size of the lumps, to completely remove the carbonic anhydride from the charge, and thereby obtain the theoretically perfect concentration of metal. The concentration is, however, considerable.

This is well shown by an example given by Dr. W. Stahl * of an ore with the following percentage composition :—

Spathic iron	72·55	Fe O CO_2	35·04 10·01 27·50
Copper pyrites	trace		
Iron pyrites	trace		
Manganese spar	15·91	Mn O CO_2	7·61 2·21 6·09
Dolomite	6·72	MgO CO_2	3·20 3·52
Calcite	2·20	CaO CO_2	1·23 0·97
Residue	3·47		
Total	100·85		

This ore was obtained in the Fischbach mine of the West Prussian Mining Company, and after calcination in the usual manner was converted into a material containing—

	Per Cent.
Iron	49·00
Manganese	10·50
Residue	4·85

On account of the high percentage of manganese, this material is well adapted for spiegeleisen manufacture.

The removal of the pyrites from the ore is not complete; copper sulphide is always met with in the calcined product, and this finally forms an undesirable constituent of the iron produced.

If suitable quantities of magnesia and of lime are present in the ores the decomposition of the pyrites is effected; magnesium sulphate and oxides of copper and of iron being formed in accordance with the following equations:—

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* *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 341.

$$3FeS_2 + 8O_2 = Fe_3O_4 + 6SO_2$$
$$6MgO + 6SO_2 + 3O_2 = 6MgSO_4$$
$$Cu_2S.Fe_2S_3 + 6O_2 = Cu_2O + Fe_2O_3 + 4\ SO$$
$$4MgO + 4SO_2 + 2O_2 = 4MgSO_4$$

It should, however, be noted that in this case but little sulphur is removed from the charge, the greater portion passing in the form of magnesium sulphate to the blast furnace, where it can again combine with the copper and iron. A material poor in sulphur could be obtained by washing out the magnesium sulphate. This would, however, be accompanied by the loss of a base, magnesia.

The Chemical Preparation of Low-Grade Manganese Ores.—W, Diehl* observes that of late years mechanical concentration of the low-grade manganese ores of Germany has been commercially unsuccessful in view of the importation of high-grade foreign ore. Messrs. Heinzerling and Staaden have, however, recently successfully introduced a method of chemical preparation which has for its aim the preparation of Mn_3O_4 from low-grade ores.

The ore is heated with hydrated magnesium chloride, or magnesium oxychloride, and steam, or may be subjected direct to the action of gaseous hydrochloric acid. The manganous chloride so produced is then decomposed by magnesia, thus regenerating the magnesium chloride, or, after evaporation and fusion, is converted into Mn_3O_4 and hydrochloric acid by the action of air and steam.

The process has hitherto been applied mainly to the deposits found in Hesse, but is also suited to other ores, and the author gives the results of some experiments proving this to be the case.

Instead of decomposing the manganous chloride formed into oxide in the manner indicated, it would be also possible to decompose it electrolytically in the presence of alkaline chlorides with the formation of metallic manganese, but the metal as produced in this manner is in a more or less finely divided form.

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* *Chemiker Zeitung*, vol. xiv. p. 668.

FUEL.

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I.—*CALORIFIC VALUE.*

Testing the Relative Value of Different Coals.—Mr. W. Kent * points out that the apparent fuel value determined by a single series of boiler tests under uniform conditions may not be the true relative value in actual use, but it depends on the condition under which the fuel is burned. To obtain the true efficiency, the conditions should suit the coal which is being tested; for instance, the extent of grate surface, amount of draught, &c., all have a considerable effect. Further than this, the author shows that, even under the same conditions of grate area and draught, a correction should be applied in many cases for the efficiency of the boiler. If the coal is not burnt sufficiently fast, or if it is burnt too fast, the boiler efficiency will vary, and this reacts on the supposed efficiency of the fuel. If, in a comparative test of two coals of approximately similar chemical composition, the apparent relative fuel value, as shown by the boiler test, differs less than the differences of boiler efficiency, then the apparent relative values should be corrected for the difference in the boiler efficiency. This rule is not, however, of general application, as it will not apply to coals which give much ash or clinker, because the grates and other conditions could not be altered so as to get the maximum boiler efficiency.

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* *The Engineering and Mining Journal*, vol. l. pp. 76–77.

Steam Boiler Experiments.—Mr. B. Donkin and Professor Kennedy [*] have carried out a large number of tests on various forms of steam boilers, and, in the account of these, a full description of the coal used is given. Nixon's navigation coal from Glamorganshire was used. Scheurer-Kestner gives a calorific value of 15,640 thermal units per lb. of coal free from ash and moisture. Calculation gives 15,560 units. The latter figure was adopted as all other determinations came very near it, and it is probably within 1 per cent. of the true value. In the calculation, water was assumed to pass away as gas, and not to give up its latent heat; the thermal values of carbon and hydrogen are taken at 15,540 and 52,200 thermal units per lb. The air required for complete combustion is 10·73 lbs. per lb. of coal free from ash, or 10·37 lbs. with 3·07 per cent. of ash. The following is the mean ultimate analysis of the dried coal:—

C.	H.	O.	N.	S.	Ash.
88·77	4·12	2·38	0·98	0·68	3·07

Professor Thompson gives the following assays:—

Volatile matter	11·72	Coke	87·262
Fixed carbon	84·05	Total sulphur	0·787
Ash	3·21	Fixed sulphur	0·098
Water	1·12	Total organic matter	95·08
Total	100·10		

The carbon value of 1 lb. of coal free from ash and moisture is 1·07 lb., and it will theoretically evaporate 16·1 lbs. of water at 212° F.

The authors then proceed to describe the methods adopted, and give fully tabulated and graphic results of the trials.

Pyrometry.—Mr. H. M. Howe [†] describes some of the latest additions to the means for measuring high temperatures. For technical purposes Professor Seger's "normal" clay pyramids and Mesuré and Nouel's pyrometric telescope should find extended application. In Le Chatelier's thermoelectric device, a wire of pure platinum welded to a wire of platinum containing 10 per cent. of rhodium forms the couple. The current generated is measured by a galvanometer which may be graduated to give the absolute temperatures. Indications given by this instrument are rapid and continuous, and may be registered in any position. Professor Seger uses slender triangular fire-clay pyramids 3 inches high, and standing on a triangular base ⅝-inch wide. The fusibility of these is graduated, and the temperature at which the point bends over and touches the surface on which the pyramid stands is selected as the point on the scale. The pyramids are simple and cheap, and should afford valuable indications if they are regularly prepared. Mesuré and Nouel's pyrometer is also described.[*]

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[*] *Engineering*, vol. l. pp. 1, 59, 122, &c.

[†] *The Engineering and Mining Journal*, vol. xlix. pp. 637-638.

This pyrometer was also described by Mesuré in a paper read before the *Société de l'Industrie Minérale.*[†]

II.—*COAL.*

The Yorkshire Coalfield.—Mr. J. W. Davis[‡] describes the fossil fish-remains of the Yorkshire coalfield. Associated with the cannel coal at Tingley, a very large number of fossils have been found. Of these, twenty-five species have been described by the author.[§] Fish-remains are also found on seven other horizons, and altogether fifty species have been recorded in this coalfield.

Mr. J. Nevin[||] discusses the difference between the seams in the northern and southern parts of the Yorkshire coalfield, as shown in some of the deeper sinkings. Several sections and a sketch-plan are given in illustration of the points advanced. The author thinks that the following conclusions may be drawn:—One or two of the thinner seams, such as the Winter coal and the Flockton Thick, are continuous, and can be identified through the whole of the country. In the northern part there are three main workable seams, the Stanley Main, Haigh Moor, and Middleton Main, with the Warren House and Beeston as second-class ones. In the southern part there are the Barnsley, Parkgate, and Silkstone, with the Swallow Wood and Thorncliff Thin as second-class ones. The workable thickness of coal, although not in the same seams, and the general thickness of the measures are much the same in both districts.

Mr. B. Holgate[¶] describes the Carboniferous strata of Leeds and its suburbs. Leeds is situated on the lower coal-measures, which are rich in ironstone of good quality. The combined thickness of these measures is about 300 feet, and includes four seams, the Better, Black, Crow, and Beeston beds. The author also describes some physical properties of the coal of this district.

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[*] *Journal of the Iron and Steel Institute*, No. I., 1889, p. 251.

[†] *Mémoires de la Société des Ingénieurs Civils*, vol. xliii. p. 538.

[‡] Paper read before the British Association (Leeds meeting).

[§] *Quarterly Journal of the Geological Society.*

[||] *Proceedings of the Federated Institution of Mining Engineers*, vol. i. pp. 215–219.

[¶] Papers read before the British Association (Leeds meeting).

The Midland Coalfields.—Mr. T. T. Wynne* discusses the probable extension of the Midland coalfields. Professor Hull in 1854 estimated that there were some 932 square miles in the northern and midland counties likely to contain coal, but covered with Permian and newer formations. Of these, 225 miles occur in the south-east of the Durham field, and 400 miles are similarly covered in the east of the Yorkshire field. Wirral and other parts of the Cheshire New Red Sandstone are probably underlain by coal-measures which connect the Flintshire and Derbyshire fields with the Lancashire fields. The Stafford, Warwick, Coalbrookdale, and Forest of Wye fields are all more or less connected. There can be but little doubt, also, that the North Staffordshire field stretches away under the Permian and the Red Clay to meet the continuation of the Lancashire field. The depth, however, of the coal can only be determined by actual experiments.

Coal from Carmaux, France.—The Carmaux Colliery,† Department Tarn, south of France, works six seams, with an aggregate thickness of 47 feet, the thickest being about 10 feet and the thinnest 6 feet. The thickness of workable coal in each seam is as follows :—

Seam A	8 feet	2 inches
,, B	6 ,,	7 ,,
,, C	9 ,,	10 ,,
,, D	7 ,,	2 ,,
,, E	9 ,,	2 ,,
F	6 ,,	6 ,,

The output in 1888 amounted to 334,500 tons, together with 26,845 tons of coke and 26,121 tons of briquettes. The average compositions of the coal and the coke are as follows :—

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* Paper read before the North Staffordshire Institute of Mining and Mechanical Engineers; *The Colliery Guardian*, vol. lx. p. 441.

† *Berg- und Hüttenmännische Zeitung*, vol. xlix. pp. 321-324.

	Lump Coal.	Washed Coal.	Coke.
Water	1·78	0·92	0·45
Carbon	83·33	81·95	93·13
Hydrogen	4·92	4·70	0·15
Oxygen	7·55	7·10	0·20
Nitrogen	1·12	0·95	...
Sulphur	0·16	0·09	0·04
Chlorine	0·08	0·06	trace
Phosphoric anhydride	0·00	trace	trace
Arsenic	0·00	0·00	0·00
Silica	1·26	2·34	2·95
Alumina	0·80	1·95	1·89
Ferric oxide	0·40	0·65	0·80
Lime	0·32	0·20	0·14
Magnesia	0·02	trace	0·01
Potash	0·27	0·19	0·09
Soda	0·11	0·10	0·06
Coke	71·42	70·60	...
Volatile constituents	25·50	24·10	...
Ash	3·08	5·30	...
Totals	100·00	100·00	...

Hygroscopity of Canadian Fuels.—Mr. G. C. Hoffmann * has conducted a large number of experiments with a series of Canadian fuels from anthracite to peat, showing the amount of water present in dry coal and in saturated coal, as well as the loss in dry air and the amount reabsorbed in a moist atmosphere.

The following are some of his results:—

Lignites retain 2·5 to 5·0 per cent., and reabsorb 10 to 14·5 per cent., of water.
Lignitic coals retain 1·0 to 2·0 per cent., and reabsorb 6·5 to 9·0 per cent., of water.
Coals retain 0·1 to 1·0 per cent., and reabsorb 1·5 to 6·0 per cent., of water.

Coal in New South Wales.—The approximate area of the Carboniferous strata is estimated at 23,950 square miles. The principal known coalfields exist along the coast to the north and south of Sydney, and also on the lines of the several railways and in the Clarence district. The mines in the immediate vicinity of Newcastle are the oldest and most important in the colony.

Mr. C. S. Wilkinson, Government Geologist, states that the coal-measures in the western districts are 480 feet in thickness, resting comformably on the marine beds of the lower coal-measures.

The total output of coal in New South Wales to December 31, 1889, was 46,751,963 tons, valued at £22,618,263. The "petroleum coal (oil shale) raised up to the same date amounted to 556,682 tons, c the value of £1,234,448.

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* *Transactions of the Royal Society of Canada*, vol. vii. pp. 41-55.

Coal from the Wallarah Colliery, on the coast, about 16 miles sout of Newcastle, has the following composition :—

Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Moisture.	Ash.
74·26	5·29	10·98	0·94	0·45	1·30	6·78

The seam from which this sample was obtained is 10 feet 6 inches i thickness.

A sample[*] of coal (I.) from the Young Wallsend Colliery, 13 mile from Newcastle, contained :—

	Fixed Carbon.	Volatile Hydrocarbons.	Moisture.	Ash.	Sulphur.
I. . .	56·98	36·35	1·04	4·96	0·67
II. . .	52·76	40·79	2·35	4·10	0·83

Sample II. was coal from the Silkstone Colliery, 9 miles from Wes Maitland.

A large number of other collieries are also described.

In a paper on the mineral resources of New South Wales, Mr. C. S Wilkinson[†] states that the measures are of Carbonifero-Permian age and cover an area of about 24,000 square miles. There are three mai series: the lower coal-measures, consisting of plant-beds interstratifie with beds containing a Carboniferous marine fauna; and the middl and upper coal-measures, consisting also of plant-beds. Glossopteris i one of the most characteristic fossil plants found in each of these series The aggregate thickness of coal in the seams worked is about 130 feet one seam discovered recently near West Maitland is over 30 feet thick Coal was first worked in the colony in the year 1836, although it wa discovered in 1796. The production for 1889 was 3,655,632 ton valued at £1,632,848. Several seams up to 5 feet thick of canne coal or boghead mineral occur in the coal-measures. This shale yield 150 gallons of crude oil, or 18,000 cubic feet of gas per ton.

Mr. H. P. Woodward[‡] publishes the following average assay c ninety-four samples of coal from New South Wales :—

Fixed Carbon.	Volatile Matter.	Water.	Ash.
58·99	29·94	2·22	8·85

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[*] *International Exhibition of Mining and Metallurgy*, London, 1890; Official Repo on the Exhibits of New South Wales.

[†] Paper read before the British Association (Leeds meeting); *Colliery Guardia* vol. lx. pp. 403–404.

[‡] *Annual General Report of the Government Geologist for West Australia* for 1888–8 Perth, 1890, p. 48.

Coal in West Australia.—Mr. H. P. Woodward * states that there are seven seams of coal on the Irwin river, of true Carboniferous age, and from 3 to 8 feet in thickness. The Carboniferous formation extends for at least 300 miles to the north of the Irwin, probably even to Kimberley.

The author gives the following analyses of lignite from Bunbury, on the Collie river. There are several seams probably of Mesozoic age:—

Description.	1.	2.	3.
Coke—			
Fixed carbon	45·03	52·87	54·17
Ash	5·08	2·56	9·31
Volatile matter			
Water	15·20	10·87	11·70
Gases, &c.	32·46	31·47	21·83
Sulphur	2·23	2·23	2·99
Totals	100·00	100·00	100·00

No. 1 was from the bed of the river, No. 2 from a depth of 17 feet in the immediate neighbourhood of No. 1, and No. 3 at a similar depth, but at a distance of 5 miles.

Other seams of lignite occur on the Fly Brook, near Augusta, at the south-west corner of the colony, but the lignite is of very poor quality, though of good appearance.

Another deposit of lignite is known to occur near the Vasse River, but the specimens hitherto examined from this district were of poor quality.

Brown-coals occur all along the southern coast of the colony, and there are some large deposits near Albany and on the river Fitzgerald, but these again have not proved good varieties.

The Fly Brook lignite, to which reference has just been made, has the following composition:—

Fixed Carbon.	Volatile Matter.	Water.	Ash.	Total.
43·52	38·23	16·40	1·85	100·00

An assay of Cretaceous lignite from the Pacific Coast of North America, shown for the sake of comparison, yielded the following results:—

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* *Annual General Report of the Government Geologist for West Australia*, Perth, 1890, p. 26.

Description.	North American Lignite.
Fixed carbon	44·14
Volatile matter	38·17
Water	14·00
Ash	3·69
Total . . .	100·00

The Fly Brook lignite resembles jet in appearance, though less hard while the woody structure is occasionally clearly visible.*

Samples derived from the Irwin coalfield were assayed in Londo by Mr. Harland and Mr. A. Wingham,† with the following results:—

Fixed Carbon.	Volatile Matter.	Water.	Ash.
41·29	28·61	17·04	13·06
43·50	32·20	12·40	11·90

The large amount of ash is probably due to the presence of extraneous earthy matter.

Coal in Victoria.—Mr. R. A. F. Murray and Mr. J. C. Newbery have carried out some tests of the lignite found at Gippsland, an give its value as compared with ordinary coal as about two to thre An assay of the lignite shows:—

Water.	Volatile Matter.	Fixed Carbon.	Ash.
25·98	31·02	40·65	2·35

Mr. J. Stirling § reports upon a 7-foot seam of lignite discovered a depth of 81 feet in the Mitchell river valley, and also refers to 12-foot bed of brown-coal in the Narracan Valley. Other thinne seams are also mentioned. These seams are near the northern boundar of the Gippsland Mesozoic area, and overlie the conglomerates an breccias immediately above the Silurian slates and sandstones.‖

Coal in New Zealand.—Coal-mines are now being worked in th provinces of Auckland, Nelson, Canterbury, and Otago, includin

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* *Annual General Report of the Government Geologist for West Australia for* 188 1889, Perth, 1890, p. 48.

† *Ibid.*, p. 58.

‡ *Reports of the Mining Registrars for the Quarter ending March* 31, 1890.

§ *Ibid.*

‖ See *Journal of the Iron and Steel Institute*, 1890, No. I. pp. 227-228.

Southland. The Mount Rochfort coalfield contains seams 10 to 40 feet in thickness, the available bituminous coal amounting to 140,000,000 tons. In the Brunner mine the working face of the seam is 18 feet high; the coal reserves in this colliery alone are estimated at 4,000,000 tons. This coal yields a vitreous coke, with a brilliant metallic lustre.

The total amount of coal raised in New Zealand up to the end of 1889 exceeds 5,000,000 tons.*

The Occurrence of Amberite in New Zealand Coal.—Amberite is a fossil gum, containing, like most bitumens, about 10 per cent. of oxygen and 10 per cent. of hydrogen. In association with the New Zealand coals very considerable quantities are obtained, generally in layers of limited extent and in nodules. Mr. T. P. Moody † describes the occurrence of this peculiar substance in a coal-seam at Kawa Kawa Colliery, Bay of Islands, New Zealand. Its chemical composition is as follows:—

Carbon.	Hydrogen.	Oxygen.
76·88	10·54	12·76

Its specific gravity is 1·034, and its hardness 2. In colour it is yellowish grey, and sometimes dark green.

The coal in which this substance is found is of Cretaceous age, with green sandstone as roof and diorite slate as floor. It is only reasonable to suppose that this and similar fossil gums are the exudations of trees that flourished at the time the deposits in which they are found were forming. The author is inclined to believe that this gum is an exudation from the Kauri pine, the main difference between it and the ordinary Kauri gum being in colour.

Coal in India.—Mr. T. D. La Touche ‡ reports on three coalfields in the Khasi Hills. The first of these, the Lairungao field, is of considerable extent, and the conditions under which the coal occurs are similar to those at the Cherra Punji field, though the coal is not of such good quality. One section shows an irregular seam of coal about 1 foot thick, then 6½ feet of carbonaceous shale overlying a 4-foot seam of coal. Estimating the workable coal at 3 feet, the field would yield about a million tons. The coal would be worked from the hillsides, or preferably from shafts about 100 feet deep.

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* *International Exhibition of Mining and Metallurgy, London*, 1890. Official Report on the New Zealand Exhibits, p. 9.

† *Proceedings of the Geologists' Association*, vol. xi. pp. 440–444.

‡ *Records of the Geological Survey of India*, vol. xxiii. pp. 120–124, with map.

The Maosandram field occupies the summit of three small knolls. In one place the seam is 7 feet thick, but an average workable thickness of 2 feet only can be reckoned on, with a total available quantity of 63,000 tons. The coal appears to be of Eocene age.

The Mao-be-lar-kar field is the smallest of the three, but has been of the most importance up to the present. At the village of the same name the coal is 8 or 9 feet thick, but only the lower 3½ feet are good enough to work. Much pyrites is contained in the coal. An estimate of the coal gives about 52,000 tons.

Mr. R. D. Oldham * gives some account of the coal deposits in a report on the geology and economic resources of the country adjoining the Sind-Pishin railway between Sharigh and Spintangi, and of the country between it and Khattan. Near Harnai there are several beds of coal, some of them thick enough to be worth working, while near Shahrig there are eight or ten much contorted seams. The coal is probably of deltaic origin. A detailed section given of the strata at Harnai shows five seams, of which the uppermost is 2 feet thick. The beds dip about 35° to the south-west, but a quantity of fairly good coal might be extracted at the surface without systematic mining. The first two of the following coals cake strongly, and give a grey ash; the other specimens sinter slightly :—

Moisture . .	2·20	3·56	8·12	8·60
Volatile matter .	40·56	42·60	37·64	34·84
Fixed carbon .	47·48	40·12	51·04	49·56
Ash	9·76	13·72	3·20	7·00

The Natal Coalfields.—A report by the locomotive superintendent of the Cape Government Railways has recently appeared. Six mines were visited, in which the coal varied from 2½ to 6½ feet in thickness; five of these mines give coal suitable for locomotive purposes. At the Dundee Company's mine the 4½-foot seam is being worked on a pillar-and-stall system. The pillars and two other seams will be removed in the future. The Ramsay and Wallsend mines give rather superior coal, but are not served by the railway. In the Newcastle mine the workings are 7 feet 8 inches high, of which 1 foot is shale. Diamond prospecting drills, boring to 200 feet, are used in Natal.†

Coal in Burma.—Coal has been found in the Upper Chindwin District, in the Panlaung tract of the Meiktila District, and at Thingadow, in the Shwebo District, besides stray outcrops in other parts of the province. Coal in the Nantabin-Paletwa valley, which is separated from the Chindwin river by a hill-range of an average height of 2000 feet, occurs in numerous seams, mostly of a very small thickness, but few exceeding 3 feet, only one measuring between 10 and 12 feet. It is found embedded in rather soft clay, which would render it difficult to extract, as timbering would be required. The main seams contain a hard coal suitable for fuel, but not suitable for coking purposes. Still, specimens submitted for analysis were pronounced equal to the average of Indian coals; none of them coking coals. But it would not be easy to quarry these seams, and in some cases tunnelling would have to be resorted to.*

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* *Records of the Geological Survey of India*, vol. xxiii. pp. 93-110, with map.

† *Cape Argus; The Iron and Coal Trades Review*, vol. xli. p. 151.

The Coal-Mining of Servia.—Major St. Gruic,† of the General Staff of the Servian Army, states that coal and lignite mining is carried on in Servia in a number of districts, which he names. The grants of coal lands worked during 1889 cover 42,175 acres. The different districts are described separately, the geological formations being also noted. The workpeople employed number only 413. Some of the coal is of good quality, yielding 80 per cent. of coke. The actual output is unknown.

Coal in Tonkin.—A full account of Tonkin and its coal deposits is given by H. Rémaury.‡ After dealing with the geography, means of communication, products, population, and history, reference is made to the geology. Above the basal granite come schists, Devonian formations, Carboniferous limestone and coalbeds, then Secondary and Tertiary strata and alluvial deposits. The seams of coal lie unconformably under a thick formation of sandstones and clays which are analogous to the Permian and Triassic formations. M. Zeiller has assigned a position for these beds, intermediate between the Trias and Jurassic. The coal-bearing beds extend over a belt of country about 120 miles long. Several concessions have been worked, one at Hon-Gay, another at Kerbao, where the combined thickness of the seams is over thirty yards. Besides these, there are others at Dong-Trieu and Tourane. Three divisions may be made in these strata. The first gives an inferior coal only; the second is the best known, and gives coal containing from 5 to 15 per cent. of volatile matter and 3 to 1 per cent. of ash. Twenty-four seams have been found. In the thir division five seams have been found at Hon-Gay, and one of these ha a thickness of four to five yards.

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* *Iron and Coal Trades Review*, vol. xli. p. 403.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 469.

‡ *Mémoires de la Société des Ingénieurs Civils*, vol. xliii. pp. 120–159, with plate.

The author then proceeds to give an account of the island of Kerbac the thickness of the various seams, and details of trials with this coa for steam generation. One shaft has been sunk to a depth of 284 feet under considerable difficulty, and several levels have been driven. I is expected that the works will be sufficiently advanced to produc 100,000 tons in 1891–2. The natives have proved to be ready an capable workmen.

Coalfields of Texas.—Mr. R. S. Weitzel* states that very littl mining has been carried on in the central coalfield of Texas. Of eigh openings, only three could be called mines, and one of these is shu down. One company produces daily from two shafts, 61 and 74 fee deep, 600 tons for locomotive purposes. A second colliery, near th former, produces 100 tons daily. A long-wall system is used, an the seam is 18 to 30 inches thick, with a 1-inch parting. The coa appears to contain much ash and sulphur, and corresponds closely t the coal at Leavenworth, Kansas. A coal of better quality has bee found in other situations. The coal in the central field is bituminous the semi-bituminous coal lies in the south-western part of the State bordering on Mexico, and covers some 3700 square miles. Two, an sometimes three, workable seams exist; the upper or middle seam varie from 18 to 58 inches in thickness, and is being worked at San Tomas It is a peculiar quality of coal, with some of the characteristics of canne It is free from sulphide of iron, but contains a considerable quantity o ash, and lacks sufficient fixed carbon to render it useful in a blas furnace. The lower seam shows outcrops 4¼ feet thick at Eagle Pas for some 10 miles. It exists, stratigraphically, some 600 feet belo the Neuces or San Tomas seam. No analyses are given of these coals but the coal of the lower seam appears to be a good commercial article

The lignitic field is large, and includes, in whole or in part, 5 counties. Four, and possibly five, seams have been recognised, one o which attains a thickness of 15 to 20 feet in places. The others var from a few inches up to 5 feet. The quality is very variable. I some places the coal is clean, and in other places it contains muc sulphur; but at present very little has been done in this field.

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* Paper read before the Ohio Institute of Mining Engineers; *The Engineering an Mining Journal*, vol. l. pp. 214–216.

The Fuels of Central Texas.—Dr. T. B. Comstock[*] discusses the relation of the fuel supply in Texas with regard to the possibility of smelting the Bessemer ores of Llano County. Charcoal may be made from the oak and mesquite, but the supply is scanty, as the densely wooded areas are small. The Llano district will probably be devoted entirely to mining, and the ores will be exported to other parts of the State. Coal is not found in the central mining region, but it is abundant over a considerable area northward. A number of workable beds occur north of the Colorado river, west of Lampasas County. The lignites of the Tertiary period are of considerable value, as the ash and the sulphur are fairly low; these are described by Mr. R. S. Law.[†] The Laredo and Eagle Pass coals may also be available.

The Choctaw Coalfield.—A detailed description of the Choctaw coalfield, with special reference to its geology, is given by Mr. H. M. Chance.[‡] The total thickness of the measures is at least 8500 feet, and consists of an alternation of slates, shales, sandstones, and coal-beds, with their accompanying under-beds of fireclay. Only one small bed of limestone was observed. The formation is divided by several beds of sandstone, from 50 to 200 feet thick, which form the ridges between the valleys. The base of the series is a sandstone-bed from 100 to 200 feet thick, immediately underlying the lowest or Grady seam. This seam has been worked at Bryan, and can be traced east and west for several miles. The dip of the seam varies from 40° at Bryan to nothing under the Kavanaugh Mountains, north of this place. The coals worked in the M'Alester, Savannah, and Lehigh districts are also principally seams lying in the lower 1500 feet of the measures. The following assays are given:—

	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
Mitchell basin . .	1·06	19·03	71·74	0·649	7·53
Grady basin . .	1·79	40·21	51·78	1·333	4·88
M'Kinney district .	1·71	38·67	51·48	1·006	7·18
M'Alester bed . .	1·80	37·17	53·40	0·896	6·72
Lehigh . . .	4·32	40·51	44·47	2·598	8·10

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[*] *The Engineering and Mining Journal*, vol. l. p. 170–171.

[†] *A Preliminary Report on the Coalfields of the Colorado River*, by R. S. Law. *First Annual Report of the Geological and Mineralogical Survey of Texas*, 1889.

[‡] *Transactions of the American Institute of Mining Engineers*, vol. xviii. pp. 653–661, with map. Compare *Journal of the Iron and Steel Institute*, No. I., 1890, p. 232.

The measures are folded into a series of anticlinals and synclinals, which are not so sharp as in the Pennsylvania anthracite beds. A generalised section of the field is given, with the approximate thickness of the various strata. A summary of this table is as follows:—

	Feet.
Shales, slates, and sandstones	1200
Mayberry coal	4–6
Shales, slates, sandstones	4050
Secor coal	2½
Slates and sandstones	1300
Norman coal	3
Slates and sandstones	600
M'Alester bed	4
Sandstones, slates, and shales	1250
Grady group, containing 6 to 12 feet of coal	100
Tobucksy sandstone	200

The Grady basin is about 6 miles long by 3 or 4 miles wide, and contains over 11,000 acres of the Grady bed. The bed averages 4 feet of coal, and never lies deeper than 600 feet.

In all these districts there appear to be two series of synclinals with their axes at an angle of about 30° to 40° with each other. This will probably have a great effect on the coal where the synclinals cross, and should therefore be taken into account when prospecting.

Puget Sound Coal.—Dr. E. W. Everett* states that several varieties of lignite and bituminous coal are found at Puget Sound, Washington, and in the vicinity. No anthracite has, however, been discovered. Lignitic coal is found in the Lake Washington, Chehalis, and Bucoda district. Semi-bituminous coal exists in the Green River and the South Prairie or Puyallup districts; the latter also produces the Wilkeson coke, which is of good quality. The Cle-elum fields include the Roslyn vein, which produced 30,000 tons in one month. Other localities are also mentioned in which coal, varying from lignite up to coal resembling anthracite, is found.

Coal in Wyoming.—The resources of the Black Hills and Big Horn country, Wyoming, are described by Mr. H. M. Chance.† The Dakota sandstone appears to conformably overlie the Mesozoic formation. It contains the coal worked near Newcastle, and also the best oil-wells are found in this stratum. The Newcastle coal furnishes coke of good quality from a seam ranging from 4 to 7½ feet in thickness. It also appears that the formation is favourable for the large production of gas and oil. Iron ores may possibly be discovered. The Dakota sandstone group consists of sandstones with intermediate beds of shales and slates, the total thickness amounting to about 300 feet. The principal coal-bed is found above the lower sandstone which immediately overlies the Jura-Triassic; it may possibly be of Cretaceous age. The coal is closely allied to the lignites, but may be classified as bituminous. The typical lignites of the Laramie formations are found in this district from the Belle Fourche west to the Big Horn Mountains, in beds from 3 or 4 up to 21 feet in thickness. These lignites average 20 per cent. of water and slack on exposure. The area of this field exceeds 7000 square miles.

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* *Tacoma News*, through *American Manufacturer*, vol. xlvii. No. 3.

† *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

Coal-Mining in Oregon.—Mr. R. H. Norton * points out that, whilst the mining industries of the State of Washington, admitted into the Union in 1888, are advancing with rapid strides, the State of Oregon, dating from 1859, is, so far as knowledge of its mineral resources is concerned, almost *terra incognita.* Thus, for the year ending June 30, 1889, the output of coal in Oregon was 44,850 tons; that of Washington for the same period was 918,344 tons, more than twenty times as much; and the statistics for 1890 will undoubtedly show a much greater difference. Yet the coalfields of Oregon are not less extensive, and probably of greater intrinsic value, than those of Washington.

The coals of Oregon, like those of Washington, vary from the crudest lignites, retaining their woody structure, up to a high grade of bituminous coal, making coke of excellent quality. Up to the present time no anthracite has been discovered in the State.

After three months' steady search in the country tributary to Yaquina Bay, the western terminus of the Oregon Pacific Railroad, the author discovered, and traced for 2 miles, a seam of excellent coal. The following is a section of the coal where it was uncovered :—

Coal	8 inches.
Black shale	2 ,,
Coal	3 feet.
Blue clay	5 ,,

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* *Transactions of the American Institute of Mining Engineers,* vol. xix. (advance proof).

An assay of the Yaquina Bay coal gave the following results :—

Fixed carbon	32·60
Volatile matter	46·20
Ash	7·10
Sulphur	1·07
Water	13·03
Total	100·00

In May 1890 samples of coal and coke were shown to the autho
which were much superior in appearance to anything he had previous
seen in the State. An examination of the property was prompt
made, and the result exceeded all expectations. The coalfield in que
tion is situated on the John Day River, east of the Cascade Mountain
and seems to be confined to a limited area (some 2000 acres), althoug
systematic exploration may disclose further deposits. The country
a high, rolling prairie, frequently broken by deep ravines. Viewe
from the summit of the coalfield, it has the appearance of a vast ocea
bearing away to south and west, and covered for hundreds of squa
miles with deposits of glacial drift, sometimes aggregating sever
hundreds of feet in thickness. This drift covers the hills to their ve
summits, thus indicating that it has been deposited since the upheav
of the underlying strata. The heavy winter rains had washed th
drift away on the south side of the claim, and exposed the upper sea
Developments on this seam proved it to be continuous and regula
It has been traced for more than a mile along the hillside, and shows
uniform thickness of about 20 feet, 14 feet of which is excellent cokir
coal. The bed has a uniform dip of about 18° to the south-east. Abo
half-way down the mountain a seam 7 feet thick was discovered, ar
about 300 feet from the base of the mountains another seam, 11 fe
thick, was exposed. At the time of the author's visit, this latter sea
had been opened by a tunnel about 60 feet long, to supply a sma
local demand.

The working of this coalfield will undoubtedly be of great benefit
the manufacturing industries of the State. The coals are all clean ar
bright, and remarkably free from sulphur and other impurities. Tin
did not permit an extended examination of the sandstones and shale
but the indications are that the coals are of Cretaceous age.

The following table gives the analyses of the various coals, all fro
outcrop samples, and also, for comparison, the official analyses of t
Coos Bay brown-coals :—

Analyses of Oregon Coals.

Locality.	Ash.	Fixed Carbon.	Volatile Matter.	Sulphur.	Water.	Coke.
Coos Bay, upper bench	8·05	34·95	41·55	2·53	15·45	none
Coos Bay, lower bench	6·18	32·40	44·15	1·37	17·27	„
Yaquina Bay	7·10	32·60	46·20	1·07	13·03	„
John Day River, discovery seam	7·20	51·00	37·20	0·60	4·00	good
John Day River, lower seam	7·26	48·19	40·00	0·60	4·55	„
John Day River, lower seam	5·76	50·67	36·80	0·79	6·77	„
John Day River, tunnel lower seam	5·95	52·41	34·45	0·65	6·54	* excel'nt
Coke from lower seam, John Day River	6·18	87·71	...	...	6·11	†

Copper in Coal.—The blue coloration which is evident when salt is thrown upon ignited coal is traced by Salet ‡ to the presence of traces of copper. He shows that copper is usually present in minute quantities in the ash derived from coal.

Boghead Mineral.—The Boghead mineral of Ruined Castle, Katoomba, New South Wales, contains :—

Fixed Carbon.	Volatile Hydrocarbons.	Moisture.	Ash.	Sulphur.
10·10	84·02	0·35	5·00	0·53

The specific gravity is 1·046.§

The Peat Deposits of the Eden Lake, Austria.—These deposits have an area of about 125 acres, and a depth of 10 feet. According to A. Aigner, || the composition of the air-dried peat is as follows :—

Carbon.	Hydrogen.	Oxygen and Nitrogen.	Sulphur.	Water.	Ash.
48·34	6·20	29·66	0·15	13·96	1·69

In this state the peat has a calorific value of 4510. A very useful appendix consists in a list of papers published on the subject of peat between the years 1823 and 1880.

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* Yield of coal in coke, 58·36 per cent.

† The coke was immersed in water on being turned out of the crucible; hence the excessive moisture.

‡ *Chemiker Zeitung*, vol. xiv. p. 407.

§ *International Exhibition of Mining and Metallurgy, London*, 1890 ; Official Report on the Exhibits of New South Wales, p. 28.

|| *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 343.

Briquette Manufacture in France.—For the manufacture briquettes in France 6 to 8 per cent. of pitch is mixed with the fin washed coal. The mixture is heated and compressed at from 1400 3000 lbs. per square inch. Occasionally less than 5 per cent. of pitc is used, but in eleven cases the average is 6·6 per cent. The Frenc Naval Department uses 8 per cent. of pitch, and no tar, as the latt causes smoke. The briquettes vary in weight from half a pound u wards, and in shape from oval briquettes to different forms of cube which may or may not be perforated. Details are given* of sever works. In the first of these semi-bituminous coal in particles from ⅛ inc in diameter to dust is mixed with 8 per cent. of pitch, and compresse at 1700 lbs. per square inch into 22-lb. blocks, in old-fashioned presse which turn out 100 tons per twenty-four hours. Twelve men a employed for two machines and their appurtenances. In the secon works fine coal is mixed with 6·5 per cent. of pitch, and compressed 1400 lbs. in two Dupuy presses. These give an out-turn of 80 to in ten hours, with two men and four boys. In the third-mentione works semi-bituminous coal from 0·08 to 0·32 inch cube, free fro dust, is mixed with 7 to 8 per cent. of pitch. For small oval briquett 3000 lbs. pressure is employed. For 2·2-lb. flat briquettes a Rober press, exerting a pressure of 2800 lbs., is used. Two other works a also mentioned, and curves are given to show the effect of varyin pressure and amount of pitch on the strength in the case of a pa ticular coal.

III.—*COKE.*

Coke in Colorado.—Mr. B. Stadtler† gives particulars of some the districts in which coal can be coked in Colorado. At Trinida south and west, the coal cokes well, but the coking qualities decrease an disappear towards the north. On the western side of the watershe coking coals are mined and coked near Durango. In the valley of th Gunnison, coal is coked near Crested Butte. In the valley of the Gran River, coke is made at several points. Coal, presumably coking, exis over large undeveloped areas in the north-western portions of the Stat The coals of eastern Colorado are all Post-Cretaceous, and have err neously been classed as lignites; generally this is true of the coa

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[*] *The Engineering and Mining Journal*, vol. l. pp. 127–129.

[†] *Annual Report of the State School of Mines*, Golden.

north of the Arkansas River, but below that line, free burning and semi-bituminous coals occur. A number of assays of various kinds of cokes are given with partial analyses of the ash:—

	Water.	Volatile Matter.	Fixed Carbon.	Ash.
Trinidad Coke	0·5	...	76·6–80·3	18·7–22·3
Durango Coke	...	...	...	11–13
Crested Butte Coke	0·32	0·49	87·02	8–13
Grand River Coke	under 1	under 2	79·76–88·58	10·1–19·1
Marion Coke	...	...	...	9·6

Coke-Making in the Western Kentucky Field.—Mr. J. B. Atkinson * deals at length with a series of experiments carried on at Earlington, Kentucky, for the investigation of the possibilities of coke manufacture in Western Kentucky. At present the coke is made only from slack which carries a high percentage of sulphur, and some method of desulphurisation was sought, but without much success. The research is, however, still proceeding. The condition and character of the coal and the mode of occurrence of the sulphur is so different to that found elsewhere that the methods usually employed have failed to give satisfaction.

The Semet-Solvay Coke Oven.—Four batteries of twenty-five each of the Semet-Solvay coke ovens are in use at the Havre Colliery, and treat 400 to 440 tons of coal daily. The cost of each oven is estimated at £184, and the condensing apparatus costs, in addition, £64. Each oven cokes a 4-ton charge in twenty-two hours. The gases from the ovens are all led through the condensers; part is returned to heat the ovens; the remainder being used for the boilers. The roof is supported by walls, against which the flues are built up with thin partitions, so that the heat readily penetrates the coal. Air for combustion is preheated in flues under the ovens. The doors have asbestos joints, to avoid luting. The coal contains:—

Water.	Tar.	Other Volatile Constituents.	Ash and Fixed Carbon.
4·5	1·5	10–11	84–83

and it yields in practice 81 to 82 per cent. of coke, 13 to 15 lbs. of ammonia, and 31 to 34 lbs. of tar per ton of coal. The outlay for labour and maintenance is about 13d. per ton, or about 3d. per to more than in an ordinary Belgian oven; whilst the value of the b products amounts to 18d.*

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* Paper read before the Engineering Association of the South-West; *Engineering and Mining Journal*, vol. xlix. p. 710.

The Bauer Coke Oven.—It is stated † that about the year 188 forty Bauer coke ovens were erected at the Carlton Ironworks, an that the following satisfactory results have been recently obtained an experimental test.

Mixtures were made of washed coking coal and unwashed no coking coal, having the following percentage composition:—

	Washed Coal.	Unwashed Coal.	Mixture.
Volatile products . .	30·45	28·84	30·35
Coke	69·55	71·16	69·65
Totals . .	100·00	100·00	100·00

124 tons of the mixture was coked in the Bauer ovens, resulting i 80 tons of lump coke and 6 tons of coke smalls, equivalent to a retur of 69·44 per cent. Excellent as was this return, it was thought tha the oven might, under more favourable conditions, have yielded ye better results. The charge was allowed to remain exactly twenty-fou hours in the oven.

The Lürmann Coke Oven.—At the collieries of the Wurm di trict, Germany, coke ovens on the Lürmann system have been in us since 1880. During the year ending June 30, 1890, a group of te such ovens produced 8850 tons of coke from 11,725·2 tons of coa The work was continuous, work having been carried on every da The charge coked consisted of 10 to 12 per cent. of pulp, and 13 to 1 of coking coal, the remainder being the badly coking coal of the Wur district.

The average daily output of an oven was 2·42 tons, the yield of cok being 65 per cent.‡

The Lares Coke Oven.—This oven has recently been introduce into the Karwin district, Austria, and there are now 124 such ovens i use. It appears to be of the horizontal type, and it is stated that it i of easy construction; that it can run for a number of years withou requiring repairs; that the gases are very evenly distributed aroun the coking chamber, giving a good even temperature; and that neither a superheating of the gas nor a stoppage of a channel from soot is possible. The charge is about 6 tons, the yield large, and the coke of good quality.*

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* *The Engineering and Mining Journal*, vol. l. pp. 165–166; illustrations.

† *Stahl und Eisen*, vol. x. p. 657.

‡ *Ibid.*, p. 821.

New Coke Oven.—C. Blauel † describes a new form of coke oven, arranged to admit of very different varieties of coal being coked without any important change in the arrangement of the oven. Thus, not only may the ordinary coking coal be treated, but even badly coking coals and mixtures of these latter with bituminous matter or other coals. The oven is a modified Coppée, having horizontal coking chambers with side and bottom flues for the combustion of the gas returned from the tar-condensers, the volatile products issuing from orifices in the roof of each coking chamber. By closing the door at one end of the coking chamber, coal may be introduced from the other side, and rammed tight against the closed door, yielding a firmer coke on heating than would otherwise be possible.

The oven may either be discharged at regular intervals, or the coking may be carried on uninterruptedly, as in Lürmann's oven; a small portion of the coked charge being withdrawn at one end of the chamber while a fresh charge of similar volume is introduced at the other, the whole charge being gradually pushed forwards.

The use of the arrangement employed for the collection of the by-products does not interfere with either of the above methods of operation. The author points out a number of advantages which these ovens possess.

Drawing Coke.—A simple device to be used when drawing coke has been invented by W. H. Dinmore, a blacksmith at Connellsville. A bar is placed in position across the door-frame of the oven, and carries a pulley by means of a chain and swivel. The scraper rests on this pulley, and can easily be manipulated.‡

Coke Oven Plant.—The No. 2 plant of the Hecla Coke Company is illustrated in the *American Manufacturer*.§ It consists of two double rows and one single row, each row containing one hundred beehive ovens. In the double rows the ovens are placed alternately so as to save filling.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 487.

† *Stahl and Eisen*, vol. x. pp. 415–419, eight illustrations.

‡ *The Engineering and Mining Journal*, vol. l. p. 51.

§ Vol. xlvii. No. 8.

Each oven is 12 feet 3 inches in diameter by 6 feet 7½ inches in heigh The rails between the blocks are laid on a falling gradient of 1 in 13 so that the waggons run by gravity. The metals on which the char ing waggons run are supported by piers built through the filling betwe the ovens, so that no weight has to be sustained by their walls.

The Adams Coke Oven.—The Adams coke oven consists esse tially of a beehive oven with a movable bottom. A vertical ra enables the bottom to be raised into position or lowered on to a truc which runs underneath. The bottom, carrying the coke with it, is ru out on the truck, and the coal is quenched and discharged witho interfering with the oven. The bottom is then replaced, and the ove is charged in the usual way. The whole operation of drawing an charging does not occupy more than fifteen minutes. The ram stand in a pit in the centre of the oven, and has a stroke of 6 feet. Th bottom is built up of wrought iron, and is covered with fire-brick. A the coke is quenched outside the oven, the hot walls of the latter a not cooled, and they accordingly last longer. Besides this, the ove does not cool appreciably during drawing, so that coal is coked suc cessfully in about twenty-four hours. Mr. J. B. Anderson * gives th following figures as a comparison between an ordinary and an Adam beehive oven:—Size, 12 by 7 feet; capacity, 113 cubic feet; averag charges, 6·14 and 3·85 tons; average produce, 4·0 and 2·5 tons o coke; average yield in each case, 65 per cent.; times drawn per week 3 and 6; cost per ton for drawing, 10·9 and 3·3 pence per ton; tim of drawing, 3·0 and 0·15 hours; average amount of coke produced pe week, 12 and 17 tons respectively. The coke is bright and silvery and very little small coke is produced.

Beehive Coke Oven.—In the Connellsville district there are 15,14 beehive ovens now in operation. The standard oven is 12 feet i diameter across the floor, and 7 feet in height from the floor to the to of the dome. Mr. J. Fulton † gives a specification and drawings for a oven of this nature. The retaining walls are to be built of sandston slabs not more than 6 inches thick; the first 2 feet are to be laid without mortar. The seats for the oven-doors are to be of dressed stone The filling under the ovens is to be made in layers not exceedin 1 foot in thickness, and is to be rammed or packed wet. The first rin of the oven is to be circular, 12 feet in diameter, built with shaped fire-bricks; the dome is to be built on centres, or otherwise, with appropriate bricks, and is to be keyed by the ring forming the charging door. The following is an estimate of the quantities for an oven of this size:—1250 lining bricks, 400 skew bricks, 2000 crown bricks, 130 tiles, jamb arch, and port ring.

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* *American Manufacturer*, vol. xlvii. No. 10; illustrations.

† *Ibid.*, No. 3.

Utilisation of Waste Heat in Coking.—According to M. Rossigneux,* the Anzin Colliery Company has erected 100 Coppée coke ovens, in four groups of 25, at Haveluy. A stack is provided for each group, and two of the groups send their flames direct to this, whilst the other two each serve to heat four boilers. The eight boilers supply steam to an engine which drives the coal-washing machinery. The author points out that the economy effected by the use of waste heat from coke ovens is the same as in the case of that from blast furnaces. The economy is well shown in a series of tests, the results of which are given in detail by the author.

IV.—*LIQUID FUEL.*

Petroleum in New Zealand.—Petroleum is found in New Zealand in three principal localities, each of which produces a different kind of oil: (1) The Sugar-Loaves, in the province of Taranaki; (2) Poverty Bay, on the east coast of the province of Auckland; and (3) Mauntaki, Waiapu, East Cape. The oil from the first-named source has a high specific gravity, 0·960 to 0·964 at 60° F. While giving a good lubricating oil, it is of little value for illuminating purposes. The second district produces a true paraffin oil resembling that from Canada. The third district produces a pale-brown transparent oil, having the specific gravity 0·829. It burns well, contains only traces of paraffin, and yields 84 per cent. of illuminating oil.†

Australian Petroleum Shale.—The following‡ is an assay of petroleum shale from Mount Hogarth:—

Fixed Carbon.	Volatile Matter.	Water.	Ash.	Sulphur.
7·764	83·200	0·268	8·768	0·000

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* *Société de l'Industrie Minérale*, May 3, 1890.

† *International Exhibition of Mining and Metallurgy, London*, 1890. Official Report on the New Zealand Exhibits, p. 9.

‡ *Mining Journal*, vol. lx. p. 1342.

The specific gravity is 1·111.

The petroleum oil cannel coal (kerosine shale) occurring at Joac Creek gives on assay:—

Fixed Carbon.	Volatile Hydrocarbons.	Ash.	Total.
11·00	82·50	6·50	100·00

The specific gravity is 1·238.[*]

Petroleum in India.—According to Mr. R. D. Oldham,[†] petroleu is being worked at Khattan, near the Sind Pishin Railway. The c both at the surface and underground, is a black, tarry, viscid substan It appears to come through the fissures from the underlying shal Four wells were being pumped, one yielding 10 barrels and the oth 3, giving an average of 7½ barrels daily. The author describes t strata of the surrounding district and discusses the occurrence of t oil, and comes to the conclusion that there is an abundant suppl which might be tapped by judicious boring.

Egyptian Petroleum.—It has long been known that petroleu occurs in considerable quantities on the shores of the Red Sea ne Djebel Seit or Gemseh, lat. 28° N., long. 33° E. This so-called Egypti oil has been the subject of a number of technical investigations.[‡] N complete analysis of the oil having yet been published, H. Kast ar A. Künkler[§] have taken the matter in hand, and give the followi figures:—

Carbon.	Hydrogen.	Oxygen.	Sulphur.	Nitrogen.	Total.
85·85	11·72	(0·92)	1·21	0·30	100·00

The oil is of a dark-brown colour; it has a specific gravity of 0·935 The flashing point is at 87° C., the ignition point at 109°, and t boiling point at 160°. On igniting the oil, there remained 0·12 p cent. of residue, consisting of lime and iron.

On account of the low proportion of volatile constituents, the oil ill adapted for the manufacture of lamp oil, but is an excellent materi for the manufacture of lubricants.

Petroleum in the Timan District.—T. Tschernyscheff[||] h examined the petroleum district of Timan, situated on the Uchta, o of the tributaries of the Ischma, which, in turn, is a tributary of the Petschora. These springs occur along an anticlinal of Upper Devonian sandstones and marl. The oil is of very much better quality than that of Baku.

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[*] *International Exhibition of Mining and Metallurgy, London*, 1890. Official Repo on the Exhibits of New South Wales, p. 4.

[†] *Records of the Geological Survey of India*, vol. xxiii. pp. 104–107, with map.

[‡] *Journal of the Iron and Steel Institute*, 1887, No. I. p. 362.

[§] *Dingler's Polytechnisches Journal*, vol. cclxxviii. pp. 34–42.

[||] *Travaux Exécutés au Timane en* 1889, through *Oesterreichische Zeitschrift für Be und Hüttenwesen*, vol. xxxviii. p. 276.

The Roumanian Oil-Field.—Mr. L. D. Galligan* describes a visit to the oil-field of Glodania, 50 miles north-east of Bucharest, in Roumania. One company has a pipe line, 3 inches in diameter and 3 miles long. Signalling on this line is performed by a number of men with brass trumpets. There are no derricks; all the oil is obtained from pits, scattered irregularly about the field. These pits are generally about a yard square, lined with wood planking and ranging in depth up to four or six hundred feet. During the sinking, ventilation is carried on by a large bellows worked by hand. The oil is raised in buckets by horse-whims. This district produces 700 to 800 barrels daily. The writer also furnishes some notes given by Messrs. Arbenz and Wolf. The oil territory extends over a distance of 250 miles, and is connected with the oil-field of Galicia. The total yearly production amounts to 45,000 tons. The production could be made much larger by employing a better system and by sinking the wells deeper. At present oil is transported by bullock waggons to the railways at great expense, and, moreover, during part of the year only, as the roads are bad, and agricultural pursuits draw off the means of transport.

The Trenton Limestone as a Source of Petroleum.—In the *Eighth Annual Report of the United States Geological Survey*,† Professor E. Orton publishes a paper, covering 180 pages, on the Trenton limestone as a source of petroleum, and on inflammable gas in Ohio and Indiana. The subject of petroleum and gas from the Trenton limestone is treated fully and thoroughly. The facts are discussed both from a geological and economic point of view.

With regard to the origin of petroleum, the author is of opinion that petroleum is derived from organic matter. It is much more largely derived from vegetable than from animal matter. Petroleum of the Pennsylvania type is derived from the organic matter of bituminous shales and is of vegetable origin, whilst that of the Canada and Lima type is derived from limestone, and is of animal origin. Petrole has been produced at normal rock temperatures (in Ohio), and is a product of the destructive distillation of bituminous shales. Las the stock of petroleum in the rocks is already practically complete.

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* *American Manufacturer*, vol. xlvii. No. 2.

† *Eighth Annual Report of the United States Geological Survey to the Secretary of the Interior*, Washington, 1890, pp. 483-663, with seven plates.

The oil and gas derived from the Trenton limestone differ from th of the Pennsylvania wells in chemical composition and in phys properties, in the horizons from which they are obtained, in structural features of the rocks that are associated with their prod tion, and most of all in the kind of rock which yields them. facts more unexpected have ever been brought to light in connect with American geology. That a well beginning in Upper Silu limestone, bored to a depth of 1500 feet, and ending in the up beds of the Trenton limestone, should produce from the latter st 5000 barrels of oil in twenty-four hours, and should maintain that of flow for a lengthy period, and that inflammable gas amounting 15,000,000 cubic feet a day should flow from similar openings un a pressure of 400 lbs. to the square inch, and continue to flow for th years, are facts difficult to reconcile with the previous knowledg this geological series. The influence of this remarkable discover oil has been felt far and wide. Borings directed specifically to Trenton limestone have been undertaken in many States. There however, nothing in the new experience to make it safe to count Trenton limestone as an oil rock in any locality unless it can be sh to have undergone dolomitic replacement, by which its porosit assured. Indeed, the author is of opinion that the Trenton limest will prove neither an oil rock nor a gas rock in any new field.

Petroleum in Peru.—Mr. E. Fowks, in a letter to *Engineeri* states that Zorritos, longitude 81° 40′ west, and latitude 3° south, is the centre of the petroleum region of northern P Surface indications of petroleum exist, and some years ago four w were put down, the largest of which produced 16,000 gallons d There are at present nine wells, with a production of 70,000 gallon refined kerosine per month. The specific gravity of the petroleu 42° B., producing 22 per cent. of light products, 29 per cent. of illumi ing oil, 16 per cent. of lubricant, and 33 per cent. of asphalt. A l tract on the shore of the Bay of Zorritos shows surface indicat on the anticlinal formed by the shore range of the Andes. T barrels of oil, or 120 gallons, are equivalent to a ton of coal.

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* Vol. l. p. 190.

Hungarian Ozokerite.—According to Thede,* this mineral yields 60 per cent. of paraffin residue, and 27 per cent. of illuminating oil. Both of these, however, are of much less value than are those obtained from brown-coal tar.

V.—*NATURAL GAS.*

Exhaustion of the Supply of Natural Gas.—Professor Edward Orton, the State geologist of Ohio, in discussing before the American Association for the Advancement of Science, at its Indianapolis meeting, the probability of the exhaustion of the supply of natural gas, said that the gas supply is rapidly and surely vanishing. Every one conversant with the facts, he thinks, agrees with him. The pressure of wells in Indiana and Ohio is steadily diminishing, the diminution having already amounted to between 30 and 40 per cent. He urges the imperative necessity of cities and States taking action to restrict wasteful use of gas, but even the strictest regulations, he says, cannot prevent the exhaustion of the supply in a few years.

In this connection it is interesting to note that the Pennsylvania Company has taken the step of refusing to sell natural gas in Erie, Pennsylvania, except by meter, charging 11¼d. per 1000 cubic feet, in order to prevent waste of the gas. No factories are to be furnished at any point on its line, as all the gas will be used for domestic purposes.†

VI.—*ARTIFICIAL GAS.*

New Gas-Producers.—E. Althans ‡ describes a new form of gas-producer. It is of the vertical cupola type with hollow walls, with a modified arrangement for the introduction of the air to be used in the manufacture of the gas. The gas issues from the producer at a high temperature. A comparison is made between the calorific value of the gas made in this producer and that of the gas from a Siemens producer of the ordinary type, the result being greatly in favour of the new producer.

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* *Zeitschrift für analytische Chemie*, 1890, p. 241.

† *Engineering and Mining Journal*, vol. l. p. 329.

‡ *Stahl und Eisen*, vol. x. pp. 397–404.

The producer, designed by Mr. C. E. Burdell, is constructed so t oil and steam are alternately introduced at the top and bottom of fuel, the oil being introduced within the fuel adjacent to its top bottom, and the steam just below the bottom and just above the of the fuel. The steam is superheated by passing it through a built into the wall of the producer.

Illustrations are also given* of M'Cullom and Burt's producer, which there are two chambers, one placed over the other. Doors placed at each end, so that charging can be performed as desired keep the chambers at a uniform heat. The upper chamber conta lime, which is used to remove the sulphur from the gas. Regenerat chambers are combined with this producer.

Smith's Gas-Producer.—A fuel gas plant, with Smith's g producer, for a rolling mill in Pennsylvania, is illustrated in *American Manufacturer.*† The producer, as previously described,‡ c sists of two Siemens' producers placed in juxtaposition, so as to fo a double breast arrangement. A modification has been introduced cooling the gas in the downcomer by means of a water jacket, inst of a water spray.

The Loomis Process of Making Gas Fuel.—Mr. R. N. Oakma describes the Loomis method of making water and producer gas. T apparatus consists of a cylindrical producer, from 7 to 10 feet diameter, and 12 to 13 feet high, lined with fire-brick; a verti boiler, an exhausting engine, an auxiliary boiler, and two gasholde The vertical boiler is multitubular, 3 feet in diameter, and from 17 20 feet high. A scrubber is used to wash the gas. Bituminous c is used, the slack working most satisfactorily. Air and fuel are bo admitted through a feed door on the top of the producer. The passes through and heats the vertical boiler. Producer-gas is obtain during four to six minutes, after which the feed door is closed, a superheated steam is sent into the base to produce water-gas duri about the same period of time. These producers have worked da for six months without drawing the fire. Producer-gas may be ma continuously. The following are analyses of the two gases :—

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* *American Manufacturer,* vol. xlvii. Nos. 4 and 5.

† Vol. xlvii. No. 8.

‡ *Journal of the Iron and Steel Institute,* 1890, No. I. p. 245.

§ *Proceedings of the Institution of Mechanical Engineers,* 1890, pp. 402–418.

Description.	Water-Gas.	Producer-Gas.
	Per cent.	Per cent.
Carbonic anhydride . .	45·0	7·4
Carbonic oxide . . .	36·6	22·5
Hydrogen	57·4	13·2
Nitrogen	1·5	56·9

Combustion in Gas-Producers and Open-Hearths.—H. von Jüptner * gives a series of calculations relating to the combustion of fuel in gas-producers and open-hearths.

The following are analyses of the coal to the consumption of which the calculations refer:—

	C.	H.	O.	N.	H_2O.	Ash.	S.	Calorific Value.
I. . .	60·91	4·23	17·98	0·71	9·92	6·25	0·53	6013
II. . .	75·55	4·54	11·38	0·46	2·44	5·63	0·60	7433

I. Coal from Leoben district; coke, free from ash, 45·50. II. Coal from the Ostrau district; coke, free from ash, 61·33. The sulphur mentioned is "combustible" sulphur.

The calculations are carried out in the manner described in previous abstracts.

The Manufacture of Water-Gas.—C. Walrand † describes an arrangement for the simultaneous manufacture of producer and water gas, the gas mixture as it leaves the producer consisting of equal parts of the two gases. It is evident that such a mixture must be of great heating power. The new producer making this gas may be fed with coke, anthracite, or non-coking coal-fuels not usually employed for this purpose. In principle the apparatus resembles the ordinary water-gas producer, except that the two gases are made simultaneously, though apart from each other.

The apparatus consists of two vertical chambers placed side by side and connected at the top by a wide tube. At the bottom is an ordinary valve as used in connection with regenerator chambers for changing the direction of the incoming air or steam into either one or other of the two chambers of the producer. In practice, when one chamber is being heated up and producer-gas being made, steam is being introduced into the other for the manufacture of water-gas, and the valves being afterwards changed, the process is continuous, t gas being practically of the same average composition throughout t operation. The following is an analysis:—

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. pp. 428 and 439.

† *L'Ancre de Saint-Dizier*, through *Stahl und Eisen*, vol. x. p. 511.

N.	H.	CO.	CO_2.
28·0	31·5	38·5	2·0

Mixed Producer and Water Gas.—W. Schmidhammer,* remar ing on the simultaneous production of producer and water gas suggested by Walrand, observes that the maximum quantity of stea which the heat evolved in the producer is capable of decomposing not more than 9·5 per cent. of the weight of the coal charged. Th would give rise, using mixed air and steam, to a gas consisting volume of 14·15 parts of producer-gas to every 1 part of hydroge By using hot blast, and by superheating the steam, the above percenta of 9·5 might be somewhat increased, but certainly not to the exte maintained by Walrand.

Water-Gas at Detroit.—At the works of the Spiral Weld Tu Company at Detroit are four producers of special design, using anthr cite, with a capacity of 300,000 cubic feet of gas per day. Water-gas made and exclusively used, the air producer-gas made during firing- not being employed. The gas is passed through scrubbers, and is th delivered to three boxes in series, in which it is purified by allowi it to pass first through a layer of lime, and then through two layers iron oxide. A fourth box is always out for cleaning, &c. For t sake of economy in storage capacity, the fuel gas is compressed to abo 30 lbs. per square inch. It is burned, however, at a pressure of lbs. The air for the combustion of the fuel gas is delivered from rotary blower under a pressure of 38 inches to a 16-inch main. T ratio of air to gas consumption is about 1 to 9, and about 30 cu feet of gas is consumed to 1 lineal foot of weld.†

VII.—*COAL MINING.*

Improvements in the Mechanical Engineering of Collierie —At the meeting of the Institution of Mechanical Engineers held Sheffield on July 29, Mr. Emerson Bainbridge ‡ pointed out that duri the last eighteen years there has been no substantial increase in the number of pits, but the rate of output has been accelerated and the shafts have become deeper. Consequently the principal questions involved in the satisfactory working of coal-mines belong rather to mechanical engineering than to mining. Mr. Bainbridge gave a description of various improvements recently introduced in connection with the sinking of shafts, pumping, winding coal, production of steam, haulage of coal, coal getting, ventilation of mines, and screening and cleaning coal.

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* *Stahl und Eisen*, vol. x. p. 623.

† *Iron Age*, vol. xlvi. p. 88.

‡ *Proceedings of the Institution of Mechanical Engineers*, 1890, pp. 360–395; with sev lates.

After having described the Poetsch freezing process for sinking shafts, the author proceeded to mention Mr. William Galloway's method of sinking and walling in a shaft simultaneously by means of guides from which the walling scaffolding is suspended. The rider consists of three principal elements, viz., a crossbar, in which there is a central opening which fits loosely round the winding rope, and two vertical legs bolted to the crossbar, having two openings for the guide ropes. A circular iron plate rests horizontally on the cap of the winding rope, and supports an indiarubber buffer. The extremities of the guides have similar buffers. The stage is permanently suspended in the shaft by the guides, and has a circular opening through which the trunk can pass. Above the stage there is a similar construction, called the "roof," to which an iron ladder provides a means of access. When the end of the winding rope is raised above the walling stage, the rider is caught up by the buffer at its end and slides on the guide ropes; and when the end of the rope passes below the stage, the rider is left standing upon the buffers at the end of the guide ropes, while the trunk can be lowered to the bottom of the shaft.

As regards the winding of coal, the old system of wooden guides is quickly giving place to wire-rope guides, of which two, three, or four are employed. At a Staffordshire colliery, where this arrangement is adopted, the cages pass each other at only a distance of 3½ inches apart. There are three guides fixed on one side only of each cage, provided with thimbles; and between the two cages two more guides are hung to prevent the cages from touching. The adoption of steel rails as guides is not to be recommended, as they cause some obstruction in the shaft, and the first cost is considerable. A good deal of attention has been paid to the counterbalancing of the full cage and the rope attached to it. This has been done in the three following ways:—Firstly, by a counterbalance weight working in a small shaft or staple, or running on a steep incline; secondly, by using a scroll-drum with varying diameters; and thirdly, by attaching to the bottom of both cages a rope about equal in length and weight to the winding rope When a large quantity of coal is drawn, a few seconds more or less in taking tubs from the cage and replacing them by empty ones has a serious effect upon the work of the day. In recent years several improvements have been made in this respect. At two of the Nunnery Collieries an effective plan has been adopted, which saves the wear of cages by reducing the shocks upon the rivets, and prolongs the life of the ropes, whilst at the same time it gives some assistance to the winding engine. This arrangement consists of four strong spiral springs, upon which the cage rests when it reaches the bottom of the shaft.

The necessity of using steam economically may be judged by the fact that the consumption of fuel at a colliery varies from 2 per cent. to about 10 per cent. of the output. Two special difficulties at a colliery are bad feed-water and the need of utilising inferior coal for boiler purposes. The latter point had to be considered in the case of the Nunnery Collieries, where six years ago new boiler plant was put down, which now constitutes one of the most complete and economical installations in the district. The coal used is of a very inferior quality, and is scarcely fit for sale, containing as it does so much ash and impurity; and hand-firing was found to be almost impossible. Experiments were therefore made with a number of mechanical stokers. After a series of very careful trials, Proctor's stokers were applied four years ago to a group of seven Lancashire boilers, and these are now working satisfactorily. These boilers consume about 60 tons of coal per day, yielding about 10 tons of ash and refuse. The ash, &c., when drawn from the fireplace is apt to damage the front of the boiler, which is therefore protected by an iron apron made in one piece. The boilers are set in a somewhat unusual way. The side flues are made larger than usual, and are fitted with doors to enable the boiler-sides to be easily swept. The return gases are allowed to impinge upon the sides of the boiler to a height of 12 inches above the water-line. An economiser is placed at the back of the boilers, which consists of 350 tubes. The gases leave the boilers at a temperature of about 400°, and reach the chimney at a temperature of about 280°. The feed-water is passed into the economiser by an exhaust injector, and reaches it at a temperature of 170°, leaving it at a temperature of about 280°.

The subject of underground haulage is a very important one, and many special systems and appliances have been developed in recent years. Steel sleepers, endless rope systems, clips of various kinds, electric motors, &c., have engaged the attention of engineers.

Very little progress has been made during the last twenty years in the replacement of manual labour by machinery for the getting or hewing of coal. The first cost of a coal-getting plant, including air-compressor, pipes, and coal-cutting machine to cut about 300 tons per day, is about £3500. There is a distinct saving of labour in the use of the machine, but this has not as yet been advantageous to the coalowner; the chief advantages are, that a larger quantity of round coal is produced, and the most arduous, and therefore the most expensive, part of a collier's work is done by machinery. Coal-cutting machines driven by electric motors are not uncommon in America, but have only recently been adopted in England. The drilling of holes in coal and stone is now performed by mechanical drills. A coal heading machine, which has already been applied on an extensive scale, has been brought out by Mr. Stanley of Nuneaton. It cuts an annular groove about 5 feet diameter around the face of the heading. leaving a core, which either falls or is broken off as the work proceeds. The coal and slack are passed back behind the machine, and loaded into tubs.

The elements of danger, waste, and inconvenience in furnace ventilation for mines have caused an almost general adoption of mechanical ventilators; and many endeavours have been made to improve the ventilating fans which were in existence twenty years ago. Several committees of mining engineers have been formed to report upon the relative merits of various machines; and at the present time a series of exhaustive experiments are being made by a committee of the North of England Institute. The principal fans now used are the Guibal fan, Walker's improved Guibal fan, Cockson's, Schiele's, Capell's, Waddell's, and Lupton's fans; of these, the first-named is the most widely used at present. Probably more progress has been made in screening and cleaning coal than in any other department of colliery engineering during the past few years; and a large number of screens, both revolving and jigging, have been introduced. Following the example of Continental engineers, there has been a considerable development of the system of carrying bands or belts, for the purpose both of sorting coal and of removing impurities. These carrying bands may be said to be confined to two descriptions, viz., the wire belt, which consists of an endless length of woven wire; and the steel-plate belt, which consists of two or three endless chains, carrying steel plates varying in width from 6 inches to 14 inches. The last point to be referred to in connection with cleaning and screening the coal is the manner in which it can be passed into the waggon with the least amount of breakage. There are four modes of doing this, which are more or less effective. The peculiar manner in which a joint in the belt renders it difficult to prevent the breakage of coal has been dealt with at the Nunnery Collieries by the adoption of a double plate.

Mining Machinery at the Paris Exhibition.—In an exhaustive paper covering 117 pages, F. Dujardin-Beaumetz * reports on the progress in mining machinery accomplished during the last ten years, as shown at the Paris Exhibition of 1889. The report is the outcome of the labours of an influential committee appointed by the French Society of Civil Engineers. It is confined to facts and descriptions; it having been found that to state the practical and theoretical reasons that led to the adoption of the different types of machinery would have occupied too much space. The report being confined to mining machinery, all accounts of the occurrence of mineral deposits or the method of working are omitted.

Each of the important exhibits is described in detail, the subjects being classed under the following heads: (1) Transmission of power; (2) Boring; (3) Sinking; (4) Winding; (5) Pumping; (6) Supporting the excavations; (7) Rock-drilling and Coal-cutting; (8) Explosives; (9) Mechanical haulage; (10) Underground transport; (11) Ventilation; (12) Safety-lamps; (13) Coal tips; (14) Mechanical preparation; (15) Patent fuel manufacture.

Pneumatic Hoisting.—The great depth attained by some of the older mines, and the still greater depth at which they must be worked in the not distant future, lend importance to the pneumatic system of hoisting. The limit is being rapidly approached beyond which the ordinary cylindrical rope cannot be used, since its weight will reach its safe tensile strength.

Taking the weight of a cast-steel winding-rope of 1⅛ inch diameter at 2 lbs. per running foot, and its breaking-strength at 84,000 lbs., it should, theoretically, sustain itself until 42,000 feet long before breaking from its own weight. But taking the usual factor of safety of 7, then the safe working-length of such a a rope would be only 6000 feet.

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* *Mémoires de la Société des Ingénieurs Civils*, vol. xliii. pp. 344–461.

If a weight of 3 tons (6000 lbs.) is now hung to the rope, which is equivalent to that of a cage of moderate capacity with its loaded trucks, the maximum length at which such a rope could be used, with the factor of safety of 7, is 3000 feet, or

$$2x + 6000 = \frac{84,000}{7} \quad \therefore x = 3000 \text{ feet.}$$

Theoretically the tapered rope has no such limit, but practically, as used at present, it has its limit, though very much exceeding that of a cylindrical rope.

The pneumatic system of hoisting is entirely free from these objections. Mr. H. A. Wheeler * has therefore studied the practical application of this system at Epinac, France, and gives a complete description of the plant. The system was introduced at the Hottinguer shaft by Z. Blanchet in 1876; but although the shaft was sunk to a depth of 2133 feet, coal has not yet been struck, and no complete test of the system has been made.

M. Blanchet's plan was to have one or two continuous air-tight sheet-iron cylinders or large tubes extending from the bottom to the top of the shaft. Within the cylinder moved a piston, to which was hung a cage with as many decks as desired, nine decks being used at Epinac, while suitable air-tight doors open out at each level for allowing the decking of the trucks. It was worked by exhausting the air from above the piston, and as the lower side was open to the atmosphere, the piston was raised by the difference in the pressure of the atmosphere and the vacuum produced by the air-pump. For lowering, it was merely necessary to allow the air to re-enter above the piston by a throttle-valve, while the speed could also be regulated by throttling the escape of the expelled air from below the piston. It is obvious that, neglecting the friction of the piston, any lifting capacity desired can be obtained for a given vacuum by merely increasing the diameter of the tube, while the speed of hoisting will depend on the capacity (size and speed) of the exhausting engine to maintain this vacuum.

The Epinac plant consisted of a tube or cylinder, 63 inches in diameter and 1979 feet in length, made of sheet-iron, 0·27 to 0·31 inch thick, in circular sections 4½ feet in length, with butt-joints for the vertical seams, secured by countersunk rivets. The sections were bolted to one another by flanges made of angle-iron, using rubber packing to make the joints tight. The alignment of the tube was

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

preserved and its weight sustained by suitably connecting it to th shaft timbers, so that the tube stood vertical, within the enclosin special timbering, without bearing any excessive weight on its base Cast-iron doors, opening outward, were placed at the landings, i being arranged at Epinac to load three decks at once, in order not t lose too much time in handling the nine trucks, as each deck onl accommodated one car. The chairs or catches for sustaining the cag at the landings passed through stuffing-boxes, to prevent any leakag of air, and were operated in the usual manner. The total weight of single tube, with all its doors, valves, chairs, hanging-rods, bolts, &c. was estimated at 342 tons, of which the tube alone amounted to 245 tons. The train, or moving members, consisted of an upper doubl piston, to which was hung the cage with its nine decks, and a lower o guiding piston, the whole having a vertical length of about 52 feet The pistons were packed with leather, backed by springs, and th whole train was made as light as possible by using steel in its construction. For indicating the position of the piston, push- or touch-button were placed along the tubes, which, on being touched by the pisto in moving past them, made an electrical connection indicated on series of tell-tale dials in the engine-room. Barometers and seconds chronometers were also used as additional safeguards for indicating th position of the cage. The latter did so, in a rough way, by the tim usually required to make a trip, while the former were connected wit the tube about every hundred yards, and so showed the progressiv position of the cage. Suitable valves at the landings, connecting wit the atmosphere and the exhaust-engine, permitted the safe and eas landing of the cage, on their being worked by the lander, whilst safety valves were used at the top and bottom of the tube to slowly check the velocity of the cage, and prevent the piston from knocking out the tube-heads, in case of inattention on the part of the lander.

Of the 64 horse-power developed by the exhaust-engine, 75 per cent. was utilised during the period of ascent; but as no useful work is done during the preliminary exhausting of the tube, the average efficiency was 56 per cent.; and as 50 per cent. of the load was coal or net weight, this gives a net efficiency of 28 per cent. of the engine-power with a single non-counterbalancing tube.

The final exhaust-engine is a duplex, direct, horizontal engine of 739 horse-power, with 46 by 46 inches steam cylinders, 46 by 113 inches air cylinders, and when making $23\frac{1}{20}$ revolutions per minute with 75 lbs. steam pressure, cutting off at $\frac{1}{3}$ stroke, has a calculated efficiency of 70 per cent. With this powerful engine the time required to make a round trip, going a distance of 1979 feet, was: For the ascent, 2 minutes 30 seconds; for the descent, 6 minutes; for making the landings, 3 minutes; total for the round trip, 11½ minutes. The load raised consisted of 11,550 lbs., or 54 per cent., dead weight, and 9900 lbs., or 46 per cent., live weight; total, 21,450 lbs.

The following is given as a comparison between the pneumatic system with its single tube and winding with tapered manilla ropes:—

Depth in Feet.	Rope-Winding.			Pneumatic Hoisting.			Coal Consumed per Ton Coal Extracted.	
	Horse-Power.			Horse-Power.				
	Expended.	Utilised.	Efficiency. Per Cent.	Expended.	Utilised.	Efficiency. Per Cent.	Ropes.	Pneumatic.
820	225	90	40	800	360	45	55 lbs.	16·5 lbs.
1640	500	180	36	862	”	42	110 ”	33·0 ”
3280	800	224	28	985	”	37	220 ”	66·0 ”

With a so much heavier investment of capital, with such a very small capacity compared with winding-engines of equal power, and with the probability of a much greater daily working expense, it is needless to say that the pneumatic system, as thus far developed, cannot compete at all with the rope system of winding, in spite of the theoretical and the practical advantages it possesses.

In conclusion, the author suggests that the present limits of American winding practice may be greatly exceeded (1) by counterbalancing the dead load, (2) by using a smaller factor of safety for the rope, (3) by the use of the best materials for the rope, and (4) by designing the cage with a minimum of weight.

Cage-Props.—Mr. E. B. Clarke* describes the Strauss system of colliery cage-props which has been in use for over three years in Belgium. During a trial of two months, 78 cages per hour were drawn, and this number was increased to 88 per hour after the adoption of these props. This is equal to from 1000 to 1100 tons per day with two-deck cages. The prop is pivoted to a link, and rests on a steel block. The link is hung on a fixed pivot and is drawn back by a lever, so as to withdraw the prop when it is desired to lower the ca The withdrawal can be performed with the whole weight of the c resting on the prop. The ascending cage knocks the prop up as passes, and then falls back on it. Two or three deck cages are read used as the prop is withdrawn, and the cage falls through the hei of one deck. A balance platform is used at the pit-bottom, so t a slight difference in the length of the rope does not affect working.

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* *Proceedings of the Federated Institution of Mining Engineers*, vol. i. pp. 209-211, illustration.

Ormerod's Safety-Catch.—J. von Hauer* describes this safe catch by the aid of several illustrations. It can be used at great spe as experience in the past has shown.

Haase's System of Sinking through Quicksand.—A shaft feet deep has recently been sunk through quicksand at the Gue Colliery, in the Cottbus district in Germany, by means of Haa system.† The chief feature in this system consists in driving dow number of wrought-iron tubes side by side, so as to form a cribbi The tubes are 13·1 feet long, 4·1 inches in diameter, and 0·2 i thick. Wooden guides are used when driving the tubes. Six were used to reach the seam. The shaft is 10·8 by 8·5 feet ins the ordinary timbering, and 9·5 by 7·2 within the tubular lini Altogether 64 tubes were required. The cost for wages was ab £222; tubes and tools, £1675; coal, £505. The removal of the c caused no deviation of the tubes, and the drainage through the was satisfactory.

The same system has successfully been adopted at Gröben to s through 23 feet of quicksand, the time occupied being 2½ months.

Working Thick Coal-Seams by Longwall.—Mr. R. M'Lare describes the system of working introduced four years ago at Balgo Colliery, Fife. The seam worked is the Dysart Main coal, which in the upper coal-measures. The field is 300 acres in extent, of wh about 40 acres are worked. Two shafts are sunk, 600 yards dist from each other. The Julian pit is 80 fathoms deep, and the Loch side pit 61 fathoms deep. Pumping machinery is fitted at both sha the amount of water to be dealt with being 700 gallons per min

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 263.

† *Zeitschrift für das Berg- Hütten und Salinenwesen*, vol. xxxviii. p. 264.

‡ *Transactions of the Mining Institute of Scotland*, vol. xii. pp. 65–71.

The output of coal is 500 tons daily. The inclination of the seam is irregular, varying from the horizontal to 1 in 2½.

By the aid of six drawings, the author gives a detailed description of the method of working employed. The advantages claimed for this method of working in thick seams are, (1) that the whole available coal is obtained; (2) that the working faces are much more easily ventilated than in the pillar-and-stall method; and (3) that, as to safety, efficiency, and economy, it will compare favourably with any of the present methods of working thick seams.

Steel Supports in Mines.—Mr. H. W. Hughes* gives his experience with the use of steel supports in mines. For bars up to 7 feet in length a section measuring 5 by 4 by ½ inches, weighing 66 lbs. per yard, is used. They cost 9s. 3½d. each, and replaced oak bars measuring 6½ inches quarter girth and costing 2s. 8d. Before definite results were obtained, the mine fired. After a lapse of nine months the mine was reopened, and it was found that the steel bars had scarcely suffered, while the timbers were much broken. Twelve-foot bars weighing 78 lbs. per yard, and costing £1, 0s. 11½d. each, are also used to replace timber 9 inches quarter girth and costing 9s. In many cases the steel bars outlasted three to four sets of timber. In one place these bars lasted thirteen weeks, whilst oak bars never lasted more than a fortnight. Where there is a heavy weight, or in return air-ways, steel bars have great advantages. They should be set carefully with an equal level bearing on both props and roof. When they take a permanent set, they should be turned over or straightened. With these precautions the author has not had a breakage. Steel props are also made, the web of the girder being cut out for a short distance and the two flanges bent round to form a flat bearing surface.

Explosives used at the Anzin Collieries.—According to M. François,† the Anzin Mining Company has for several months employed in fiery collieries the following explosives:—

(1.) 20 per cent. of gelatinised nitro-glycerine with 80 per cent. of ammonium nitrate.
(2.) 30 per cent. of gelatinised nitro-glycerine with 70 per cent. of ammonium nitrate.
(3.) 10 per cent. of octo-nitric cotton with 90 per cent. of ammonium nitrate.

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* *Journal of the British Society of Mining Students*, vol. xiii. pp. 18–19.

† *Société de l'Industrie Minérale*, 1890, March 16.

More than 30 tons of these explosives have been consumed with a single accident. No practical inconvenience has been met with, the cost of working is a trifle less than in the case of the ordin explosives.

Experiments on Explosives.—Mr. F. W. Clark* summarises results of a series of experiments, carried out under his supervisi by Mr. R. C. Williams and Mr. J. B. Seagar, to determine the relat strength of nitro-glycerine and other explosives. The tests were m by exploding them in lead cylinders, cast at the lowest possible tempe ture, 5½ inches high and 5¼ inches in diameter, with a central bore inches deep by ⅝ inch in diameter. The explosive was tamped w sand, and the ends of the lead block were held between iron pla wedged up tight in iron rings. The volume of the hole before a after explosion formed a criterion of the value of the explosive. Nit glycerine, forcite, ætna, atlas, gelatine, gun-cotton, rackarock, picr powder, dynamite, &c., were used. Several gunpowders were a tested. Full details are given of the results. The author belie that an explosive base, when used as an absorbent for nitro-glyceri will only increase the strength of the latter if it is so compounded to detonate by itself; otherwise it may act as an inert base and decre the strength of the explosion.

Silesite, a new explosive, consists of 60 parts potassium chlor 10 of antimony sulphide (Sb_2S_5), and 30 of sugar.

A case is mentioned of poisoning of workmen using roburite. T men recovered, but slowly.†

Extensive and comparative trials have been made with fortis Argenteuil, Boulogne-sur-Mer, Lessines, and Micheroux. At t Argenteuil quarries near Paris, 3 lbs. of the fortis powder were pla in a hole in a large block of stone 1412 cubic feet in size, and on t charge being fired by a simple fuse, the block was completely brol into pieces about 1 cubic yard in size. 1¾ lb. placed in another blo of 1483 cubic feet broke it into blocks of about 1 and 2 cubic yar 6½ lbs. of the explosive detached from the quarry a block about 3 cubic yards in size. Favourable results were also obtained by the u of fortis in quarries at Lessines, and in coal-mines at Michero From experiments made at the Marquise quarries, near Boulog sur-Mer, it is calculated from the work done that the cost per cubic yard displaced was ½d. for fortis, ¾d. for ordinary powder, and 1¼d. for dynamite No. 1, showing a great economy in favour of fortis. Practical experiments have also been made with it in England at quarries belonging to the Mount Sorrel Granite Company, Loughborough, and at the Bolehill quarries, Crooks, near Sheffield. In the former set of trials the results went to show that fortis powder did from two to two and a half times the work of ordinary English blasting powder, and that the stone was displaced in large blocks.*

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (adva proof).

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 451.

Timbering in Collieries.—Mr. R. Martin † gives a detailed description of the manner in which the roof at the working face is secured at Straiton and Pentland. A pillar-and-stall system is employed in a 6-foot seam lying at 30° dip. The coal is worked from levels 30 to 60 fathoms apart, on an incline 400 fathoms deep on the plane. The pillars increase in size towards the deep, from 26 by 40 feet at 60 fathoms vertical, to 36 by 60 feet at 170 fathoms vertical depth. Both the roof and floor are bad, but the roof is partly protected by a thin bed of shale. Four-inch round props are set at right angles to the roof in double rows, 4 feet apart up the hill, and 2¾ to 4 feet across. In the deeper levels they are 3 feet apart. They are set 9 feet from the face. No spragging is required. For disposal of the dirt, planks are nailed to each side-row of props, and the dirt is stowed behind. The central division contains a shoot laid with steel sheets for passing the shale down to the foot. The miner has to timber his own face, and the condition of the workings is checked every two or three days, at a cost of 0·2 penny per ton. Props cost 0·8 and other timber 1·26 penny per ton. During five years only one fatal accident and thirteen other accidents occurred, the total output being about 1,000,000 tons, and the average number of workers being 527.

The Walker Shutter for Guibal Fans.—Mr. E. R. Walker ‡ describes the Walker anti-vibration regulating shutter or slide for Guibal or other enclosed fans. In Belgium the average life of fan-shafts was twelve to fifteen years, their breakage and the loosening of bolts and rivets being attributed to the excessive vibration. The shape of the shutter removes the shock due to the sudden cut-off of the delivery when a blade passes the shutter. Besides the V form, otl shapes may be used which permit the gradual discharge from the fa vanes into the chimney. The invention has permitted the use of smal fans and higher velocities, with a proportionate increase of exhausti capacity. At the same time there is greater ease in working a reduction of repairs.

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* *Industries*, vol. ix. pp. 339–340.

† *Transactions of the Mining Institute of Scotland*, vol. xii. pp. 58–64, illustrations.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

Safety-Lamp Tests.—A number of experiments with safety-lan have recently been made by Mr. W. Clifford and others. The lan which stood without firing the severest tests, but with varying degr of satisfaction, were Ashworth's Mueseler, Fumat Bennet No. Thomas Marshall, and Clifford, being two more lamps than could found to stand the same tests two years ago.*

New Safety-Lamps.—Mr. T. Thomas's safety-lamp reduces t velocity of the air-current by means of a number of deflecting chamb and passages. The air enters by two rows of holes at the base of t shield, and passes through two annular chambers, from the second which part of the air ascends between the inner and outer shield. conical chimney is placed over the flame, and leads the hot air into t inner shield, from which it passes to the outer shield and from t lamp. Gauze rings are placed at the inlets. A special lock is a used. A pivoted bar is forced by a spring into a series of holes, a is so mounted that it allows the lamp to be screwed up, but it cann be unscrewed till a key is employed to liberate this lever or pawl.†

E. Homann ‡ describes a safety-lamp designed by Messrs. Postol and Eliasch. The improvement consists in the locking of the lar and an arrangement for putting out the light. The locking is effect by two screws of equal size, but wound in opposite directions. Neith of these can move unless the other is turned simultaneously, but in t opposite direction. With these exceptions, the lamp is identical w the ordinary Mueseler lamp in general use in the Ostrau-Karwin mini district.

Miner's Electric Lamp.—Chansselle § describes the miner's elect lamp devised by C. Rousseau. It contains four Planté accumulato

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[*] *The Iron and Coal Trades Review*, vol. xli. p. 153.

[†] *The Colliery Guardian*, vol. lx. p. 247, illustration.

[‡] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 372; th illustrations.

[§] Paper read before the *Société de l'Industrie Minérale*, June 7, 1890.

and carries a small incandescent lamp, protected by an outer glass. The weight is 4½ lbs., and it gives 11 hours' light. The cost is 24s. It is of the same dimensions as the Mueseler and Marsaut lamps.

Experiments on Fire-Damp Mixtures.—A fire-damp committee, composed of Mallard, Le Chatelier, and Chesneau, have made a series of experiments to determine whether mixtures of fire-damp and air can be exploded by sparks from the workmen's tools. For the purposes of experiment, mixtures of pure marsh gas and air, with or without admixture of illuminating gas, were used. The mixture was made in wooden boxes, placed against blocks of stone, on which the picks could be struck to produce sparks. With mixtures of marsh gas and air no explosions could be produced, but mixtures of illuminating gas and air were easily exploded. When equal volumes of illuminating and marsh gas were mixed with air, ignition sometimes resulted from the sparks, but with a less percentage no explosion resulted. As ordinary fire-damp does not contain more than 4 per cent. of gas other than pure marsh gas, the committee came to the conclusion that sparks from the tools are incapable of igniting explosive mixtures of fire-damp and air. The tools used were picks with removable steel points and iron picks. Besides iron and steel, manganese steel with 13 per cent. of manganese was used; also aluminium bronze, with 8 per cent. of aluminium and 2 per cent. of silicon. The sparks from manganese steel were greater in number and also hotter than those from iron, and accordingly they ignited the gas more easily. On the other hand, the aluminium bronze picks were nearly as hard as iron, but gave no sparks, and would not ignite the mixtures.*

The Detection of Fire-Damp.—The arrangement designed for this purpose by E. Stern † consists of a porous clay cylinder, through which the fire-damp passes, and induces, with increasing pressure, the expansion of a thin metallic membrane. With still increasing pressure this membrane expands until, touching a contact screw, it closes an electric circuit and rings an alarm. The position of the contact screw may be so arranged as to show the presence of either 1 or 2 per cent. of gas, or of 20 per cent. or more.

Mr. H. N. Warren ‡ proposes the use of platinum black on asbestos.

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* *Le Génie Civil*, vol. xvii. p. 238.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 377.

‡ *The Engineering and Mining Journal*, vol. l. p. 318.

The latter material is soaked in a solution of platinum oxalate ar ignited. When the prepared asbestos is heated to 80° F. in tl presence of air containing 0·5 per cent. of coal-gas, it becomes inca descent.

Fire-Damp Accidents in Mines.—Coste * has tabulated tl accidents from fire-damp in French coal-mines between 1884 and 188 Two explosions of gas from old workings are ascribed to the gas gen rated by decomposition of wood, as gas in those pits is absolute unknown. Other explosions are abscribed to powder. The followi shows the tabulated results of the investigation:—

	Number of Accidents.	Killed.	Wounded.
Explosions of fire-damp produced by—			
Blasting	16	61	42
Open lights	16	3	22
Open or imperfect lamps . . .	13	2	16
Undetermined	4	103	8
After-damp	1	1	...

Fireless Locomotive for Mines.—C. Rolland † has construct a fireless locomotive for use in the collieries at Mons, Belgium. It provided with a tank holding 19½ cubic feet of water heated to 205° C that is to say, at an absolute tension of 16 atmospheres. The heati is effected by means of steam jets in a boiler at the surface. Tl suffices for an ordinary run of 1½ to 2 miles. By the employment this superheated water, a considerable amount of work may be stor in the form of heat in a comparatively small space, and this heat grad ally evaporates the water required for driving the engine. The reserv has a capacity of 19·43 cubic feet, the locomotive works with 6 hor power at a speed of 6½ feet per second, whilst the speed of a horse generally taken at 3 to 3¼ feet per second. Thus, working day a night, one locomotive takes the place of 12 to 18 horses, and al renders a number of workmen unnecessary.

According to an estimate for a mine 600 yards in depth, with haulage distance 600 yards in length, the cost of haulage with the fi less locomotive is £196 annually, whilst that with horses is £44 Thus there is an annual saving of £244.

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* *Le Génie Civil*, vol. xvii. pp. 249–250.

† *Revue Universelle des Mines*, vol. viii. pp. 229–239; *Dingler's Polytechnisc Journal*, vol. cclxxvii. Part iv.

Besides the direct economy, there are other advantages accruing from the use of the fireless locomotive in collieries. These are: (1) absolute safety from the dangers and discomforts of fire and smoke; (2) preservation of the mine in hygienic condition on account of the absence of horses and their stables; (3) absence of all the incidental expenses associated with horse-haulage; and (4) low consumption of steam, and good ventilation caused by the movement of the air-current created by the locomotive.

The lightest type of locomotive built at the Hohenzollern Works for this use is 9920 lbs. The author's locomotive only weighs 6610 lbs. For a track with a gauge of 23·62 inches the breadth of the engine is 32·29 inches, and its length 9 feet 10 inches. An automatic steam-pressure regulator is provided, and also means whereby the driver can control the working. In conclusion, the author proceeds to calculate the efficiency of the engine.

Petroleum Engines in Mines.—The arbitrators have decided the question raised by the inspectors of mines on the use of petroleum engines in mines, and declare that their use is not dangerous. A series of experiments have been carried out at the maker's works, and evidence was taken. A number of recommendations are made as to the carriage and storage of petroleum underground. In the course of the proceedings it was stated that there are only three or four mines where these engines are in use, but that the engines possessed considerable advantages for hauling, pumping, and drilling in underground work.*

The Distribution of Electricity in Mining.—The distribution of electrical energy in mines is dealt with by Mr. A. T. Snell.† After describing the various forms of winding used for dynamos and motors, such as series, shunt, and compound winding, the author gives a number of curves to illustrate their properties. There are two forms of transmission which can be employed, and these are constant current and constant potential. The first of these is not likely to be much employed, as it requires high-tension currents. The constant potential system of transmission employs shunt or compound dynamos, preferably the former. The advantages are as follows:—A constant difference of potential is maintained at any centre. Series, shunt, or compound motors can be used as the work requires. The plant can b increased at any time by coupling additional dynamos on to the omnibu mains. Various sizes of motors can be used, and power can readily b taken to any part of the pit by temporary cables. In case of acciden the damaged cables or machines can be disconnected from the main without affecting the rest of the plant; the system can also be use for lighting. The chief drawback is the cost of the large copper main In order to obviate this, the author proposes a scheme in which tran formers are used. The size of the conductors depends on the amou of current carried by them. By increasing the voltage, as far as safe, the diameter of the conductors is diminished. This current comparatively high tension is used at the surface and over a limit area at the pit-bottom. Beyond this limit, it is reduced to a low tension current, by means of transformers. Then it can safely conveyed to any workings, and naked or uninsulated returns may used if proper insulation is employed to prevent short circuiting in th extended area. Hitherto the author has not used currents of mo than 725 volts underground, but probably not more than 500 volts wou be adopted in the extended system; and even that voltage is too hi for running small motors. The transformers, which practically consi of a combined motor and generator, require no attention beyond oili and cleaning occasionally. The extra cost is about £8 per horse-pow per transformer, but this must be set off against the saving in t conductors and motors. Messrs. Immisch & Co. have driven lo tension dynamos off the shafts of the large pump motors, but this not so generally applicable as the above system. Transformers a also applicable to constant current systems.

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* *Iron and Steel Trades Journal*, vol. xlvii. p. 335.

† *Proceedings of the Federated Institution of Mining Engineers*, vol. i. pp. 141-156.

Alternating current motors have been made and used with succe in some cases, but there are disadvantages in employing them f mining. Transformers for alternating currents contain no movi parts, and will certainly be employed when alternating currents are use

It is pointed out that the use of electric machinery is generally sa in main intakes and in places where open lights are used, but t sparking is certainly dangerous in fiery mines.

Electric Power Transmission in Mining Operations.—M H. C. Spaulding* describes several applications of electric pow transmission in mining operations. Drilling is first considered, a illustrations are given of a portable diamond-drill and a percussive rock-drill. Electric coal-cutting machinery is next dealt with, and a description is given of the Hercules machine, in which a series of rotary drills driven by Tesla motors are carried on a frame which is fed forward so as to undercut the coal. The author then describes the electric plant at the Erie Colliery, Scranton, and also some electric-power hoists and pumps. A pump is shown in which the motor and the pump are combined in one machine, and a series of tests with a pump of this type is given. Hitherto pumps have only been driven from an electric motor by gearing of some kind, such as belt or rope gearing. With regard to the danger of electric installations, it is shown that a limit of 250 volts can produce no more physical injury than a hot steam pipe. No sparking should occur if the plant is properly designed; and accidental break-downs, which are not more likely to occur than in other systems of power transmission, are more easily repaired.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (adva proof).

Appended to Mr. Spaulding's paper are several communications. The first of these is by Mr. C. J. Van Depoele on the electro-magnetic reciprocating engine. This machine utilises the action of a solenoid on an iron core. When the current in the solenoid is made or broken, the core is alternately attracted and repelled. The successful application of this principle depends on the construction of an electric generator which gives currents rising and falling at a definite speed. As applied to a rock-drill, the bit is simply attached to the core, and the solenoid is connected by suitable cables with the generator. Switch-boxes are placed on the cables, and a transformer system may be used to convey the current.

The second communication is by Mr. J. S. Doe, and deals with the practical application of electricity to coal-mining. Twenty-three machines for under-cutting coal have been installed by the Jeffrey Company. Reference is also made to the application of electric power to drills and to haulage. Especial attention is paid to the use of storage batteries for haulage purposes. As a rule, the weight of the batteries increases the size and weight of the locomotive too largely for general use. This increase necessitates a good road and heavy rails, which causes many disadvantages in a colliery. On the other hand, small motors of 5 horse-power on a locomotive whose weight, including the storage cells, is 5100 lbs. may be used with advantage for haulage in distant parts of the mine where the cables are not carried. Assuming the first cost of this locomotive to be

£460, and that it costs £8 per horse-power per year to charge the cell the expense may be estimated at £362 per year. The equivaler expense with three mules is £408. The true place for accumulato at present is in lighting.

Mr. C. E. Doolittle describes the electric power transmission Aspen, Colorado. Eight Pelton water-wheels of 150 horse-power eac are driven by water at a pressure of 380 lbs. per square inch, and serv to drive the dynamos which supply the electric lighting, tramway hoists, and other plant in the town.

The Use of Electricity in Mining.—The plant at the Monong hela Gas Coal Company's colliery in Pennsylvania consists of two 5 horse-power engines, with cylinders 12 by 20 inches, and one 3 horse-power Westinghouse dynamo, which generates a current of 35 volts. This dynamo is used to drive a fan, a pump, and six Hercul mining machines. A 3-horse-power Tesla motor is used to drive 12-foot Pollock fan, which delivers 22,000 cubic feet of air per minut This fan is situated at the bottom of a shaft 75 feet deep, and can used to compress or exhaust air as desired by the arrangement of th air-doors. The pump is centrifugal, and is mounted on a movab truck, which also carries a 3-horse-power Tesla motor. Each coa cutting machine is driven by a 3-horse-power Tesla motor. Th machine and motor complete weighs about 1000 lbs., and will undercu 36 inches wide by 42 inches deep and 3 inches high at each operatio One man, with this machine, will average 43 tons of coal in ten hour A record of the various machines over five weeks is given.[*]

Electric Mining Signals.—Mr. J. Kean[†] describes a new lon distance electric bell for mining signals. A special form of relay used, so that only one battery is required for working the line-circu and the bell. The relay consists of an iron frame, to which is attache a single-pole electro-magnet. When the line-wires are brought in contact, a feeble current from the battery flows through them and th electro-magnet which is included in the circuit. This causes th magnet to attract its armature, which is attached to a metal sprin The latter makes contact with a platinum-pointed screw, complet the local circuit, and so rings the bell. Either a single-stroke or trembling bell may be used. The ordinary direct acting system of bells, and that of bells operated by a separate relay, are also described.

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[*] *American Manufacturer*, vol. xlvii. No. 7.

[†] *Transactions of the Mining Institute of Scotland*, vol. xii. pp. 42–51, illustrations.

Locust Mountain Tunnel.—A tunnel 5165·2 feet long has been driven through the Locust Mountain for the purpose of draining the Centralia coal-basin in Pennsylvania. The work was heavy, owing to the amount of water encountered, but the junction was made on July 1, 1890, the commencement having been made ten months previously in April 1889. The tunnel is 7 feet high and 11 feet wide, with a ditch at the bottom 4 feet wide and 2 feet deep. The rock is a hard, fine conglomerate. The plant consumed 3385 tons of coal, and the expenses were as follows:—

Plant and repairs	£6,912
Powder and explosives	6,036
Oil, lights, &c.	552
Labour	11,944
Total	£25,444

The maximum distance driven in any month was 281 feet at the south end, and 238 at the north end.*

VIII.—*COAL-WASHING.*

Coal-Washer.—M. Max Evrard † describes a modification of the ordinary piston or hydraulic jigger having an arrangement for scraping the surface and removing the top of the washed layer of material under treatment. A rectangular sieve 10 by 3½ feet is fixed on a pyramidal hutch, and has a plunger-box on one side, and a continuous, adjustable discharge opening on the other. The plunger is circular and smaller in area than the sieve. It is worked by an adjustable excentric, and is provided with an air-clack. The particular novelty in this machine consists in the scraper-frame, which is formed somewhat like a harrow, and is suspended by jointed rods. It receives a slow forward and quick return motion by means of a counterweighted lever and cam. The frame is larger than the sieve, and is connected with the slide which closes the feed-hopper, so that the fresh material

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* *Miner's Journal, Pottsville,* through *The Engineering and Mining Journal,* vol. l. p. 101.

† *Bulletin de la Société de l'Industrie Minérale,* vol. iii. p. 317.

is fed at the beginning of the stroke. The length of stroke
inches, and the teeth on the forward stroke drag the finer parts c
material forward, and disturb the material six times during its t
along the 10-foot sieve. The suspension rods are arranged so tha
scrapers are lifted clear of the material during the return stroke, u
very dirty material is being treated.

The dirt from the hutch is discharged at intervals through pi
the bottom. When unclassified coal is treated, the washed mate
subjected to a final screening, giving lump coal and slack with 1
cent. of ash. The fine coal, raked off by the last and deepest tee
the scraper, is pushed over a draining-apron into waggons.

These machines are worked at 43 to 45 strokes per minute
the expenditure of 4 to 6 horse-power per double machine, and av
15 tons per hour. This plant has been or is being adopted a
collieries in France, four in Belgium, and three in Spain.

Sifting of Anthracite.—A committee, representing 90 per
of the anthracite output of Pennsylvania, recommended on Nove
7, 1890, the adoption of a uniform size of mesh for screens. The fo
ing sizes were selected, and will go into effect in January 1891 :—

Egg,	through	2¾	inches,	and over	2	inches.
Stove,	,,	2	,,	,,	1¼	,,
Chesnut,	,,	1¼	,,	,,	¾	,,
Pea,	,,	¾	,,	,,	½	,,
Buckwheat,	,,	½	,,	,,	¼	,,

The small-stove size was abolished.*

Coal-Tipping Device.—Illustrations are given in the *Engin*
and Mining Journal † of Malissard-Taza's appliance for emptyin
sized coal waggons. A movable section of the track rocks r
an excentrically placed pivot, so that the waggon and the trac
together, being automatically overturned by the weight of the wa
A heavy pendulum, hung beneath the platform, retards the de
as it tips, and aids the return of the empty waggon. The pend
device is most efficient at the points where the counterbalan
required, as it retards the fall near its end, and assists the r
most powerfully at its beginning. In addition, a hydraulic bra
used. This consists of a hydraulic cylinder with its ends conn

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* *Engineering and Mining Journal*, vol. l. p. 581.

† Vol. l. pp. 129–130.

through a pipe and stop-cock which regulates the flow of water from one side of the piston to the other, as the latter is moved. The piston is connected to the platform by a link attached to the end of the piston-rod. The waggon is held on the platform by a couple of supports worked by a hand-wheel. Holding-bolts, movable shoots, and gates are also provided.

Coal-Lowering Apparatus.—Mr. C. Soar * describes a coal-lowering apparatus which has been designed by him, and has already been at work for nine months. It is intended to be employed instead of the adjustably inclined plate which is used at the end of screens and travelling-belts. To all practical intents, the device consists of a bucket-elevator arranged to lower the coal from the belt into the truck. A number of shelves are mounted on endless chains, which are driven at a speed proportionate to that of the sorting-belt by means of an endless chain passing round a sprocket wheel on the belt drum. This latter chain also passes over tension pulleys, and the whole device is suspended by means of counterweights, so that it can be vertically adjusted in its guides without stopping or altering the relative position of the shelves and the sorting-belt.

Coal-Tip.—A coal-tip of recent design at Cardiff has put as much as 300 tons of coal on board ship in half an hour. Ten-ton railway waggons are run on to a hydraulic tipping-table with four lifting rams. The cradle has a maximum lift of 37 feet. Coal-shoots and anti-breakage arrangements are provided. The framing is of wrought iron.†

Steam Elevators at the Commentry Collieries.—The elevators employed for raising the coal in the operations performed at the surface are described by Caillot.‡ Each elevator consists of a vertical steam cylinder, the piston-rod of which drives a drum on which two wire ropes are wound in opposite directions. The ropes pass over pulleys, and are attached to the cages. The cylinder has a diameter of 17¾ inches, and a stroke of 75 inches. The drum has a diameter of 6½ feet. The stroke of the cages is 35 feet, and the weight of the live load raised is 880 lbs.

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* *Proceedings of the Federated Institution of Mining Engineers*, vol. i. pp. 183–184; three plates.

§ *The Engineer*, vol. lxx. p. 211; one illustration.

‡ Paper read before the *Société de l'Industrie Minérale; Mémoires de la Société des Ingénieurs Civils*, vol. xliii. p. 539.

There is another elevator for waggons with a capacity of 70 cu feet, raising 3 tons a height of 37 feet, with a cylinder of 23½ inc in diameter, and a stroke of 75 inches.

The valves are worked by hand. Though they consume a c siderable amount of steam, the elevators present the advantage great simplicity.

Mechanical Screens for Coal.—Mr. E. B. Wain * gives a desc tion of two screens for coal which have been erected at a coll in the South Staffordshire district. These screens are hung in sli and driven from the ends. In place, however, of the cams which generally used, a simple crank motion has been introduced with mar improvement. The sharp return of the cranks from the centre p gives an intermittent outward motion, which allows a flatter grad and slower speed than where the smoother motion given by cam used, and at the same time separates the coal quite as effectually. screen makes three sizes—coal, cobbles, and slack. The first screen feet wide, and the second 6 inches wider, to allow the former to work side it. The screens are made of ⅜-inch iron plates, with 3-inch by ½- iron framing. A hole (in this case 5 feet square) to allow of s wire grids is left in the pan-bottom, and the grids are fastened screw pins. This allows the grids to be speedily changed where sizes have to be varied to suit different markets. The screen h gradient of 7 inches per yard. The pans are carried by hangers inches by ½ inch) from a 1½-inch round-iron shaft lying on the tim bearers. The engines are two 6-inch diameter cylinders, with 9- stroke, running at the rate of 120 strokes per minute, with a st pressure of 60 lbs. per square inch. The throw on the screens inches. The quantity passed by this screen has exceeded 800 ton eight hours, and labour for banking and screening this quantit 0·77d. per ton. This screen has been built under very favour circumstances; *i.e.*, where there is ample bank height. Where, h ever, the height is less, a modification of this plan is necess The large mesh-screen might in this case be placed above the sl screen, and the slack taken to the third road by a back-shoot. author has recently erected a modification of this screen to m three sizes from a pit bank, only 16 feet above the rail-level of siding. The coal screened by it is a high-class house coal, from w it is necessary to very carefully pick out all pieces of dirt or inferior coal. The principal working parts of the screen are similar to those of the screen just described, but the arrangement of the pans is altered. The pans, which have a gradient of 7 inches per yard, are so fixed that the coal and cobbles are delivered to the two outside roads, and the slack to the middle one. Balanced shoots are fixed to allow for the picking. An important feature in these shoots is a loose door in the shoot itself, which allows both sides of the truck to be loaded evenly, and so saves handling the coal. This screen is driven by a 6½-inch single cylinder engine, 7-inch stroke, running at 120 revolutions per minute. The throw on the pans is 3 inches. Running at the above speed the screen will pass upwards of 100 tons per hour. In order to steady the coal over the screen when leaving the tipper shoot a simple but most effective addition has been made. This is a wire brush made from all-steel ropes, untwisted and threaded through a 3-inch plank. This not only steadies the coal on the screen, but also sweeps off any slack there might be lying on the large lumps, so that it is not carried by them into the coal truck. The advantages of the last type of mechanical screen are, that it is extremely simple, and consequently the first cost is small; that the working parts are few, and there is nothing to get out of order; that a very large quantity can be passed, which reduces the labour cost of screening; that it is thoroughly efficient, and that the sizes made may be easily varied to suit different markets by simply changing the grids; that the breakage of coal on the screen is reduced to a minimum; that the two pans working in opposite directions counterbalance each other perfectly, and so reduce the engine power required, and that there is very little noise and vibration.

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* Paper read before the North Staffordshire Institute of Mining Engineers, Ma 1890.

Coal-Breaking Works at Drifton and the Cross Creek Collieries.—In a lengthy paper of seventy-seven pages, illustrated with forty-two plates, Mr. E. B. Coxe* describes the breaking plant at Drifton and some of the machinery used for handling and preparing coal at the Cross Creek collieries, Pennsylvania. The subject is dealt with under the following heads:—The latest design of some of the machinery used; elevating, conveying, and transporting the coal and slate, and raising the coal from the mines to the top of the works; the building as a structure; and the preparation of the coal as effected in the works.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

Anthracite as it comes from the mines is not marketable. It be broken to uniform size, and must be free from slate and Machinery for sizing may be divided into two classes, fixed or mov bars, and fixed or movable screens. Of the first class there are types, namely, adjustable bars fixed at both ends, finger bars supp at one end, and oscillating bars. The finger bars are tapered secured at the upper end only, so that long pieces are not like catch and clog the openings. The oscillating bars are also improved construction, as they are caused, by means of suspen links and excentrics, to take an elliptical instead of a circular mo With this construction the coal is not thrown up and down so when it is rapidly fed forward, as in the Briart construction. O second class there are also three types—fixed screens, revolving scr and gyrating screens. The problem of constructing a gyrating sc when the screen is large and has to make many sizes, is to supp so that it will gyrate easily and safely, and that it will be self-conta This is done by supporting the screens on the base by means of or more double cones, while the motion of gyration is given by a journalled in the base. Suitable surfaces are provided on the bas under the screen for the cones to bear on, and several means ca employed for keeping the cones in position. In these screens point moves on circles, which are not, however, concentric. With the radius is generally 2 inches. A counterweight is used to cou balance the centrifugal force, or two screens may be driven by cr at 180° with each other. In this machine, the screening boxes by 6 feet by 2 to 4 feet high, and contain 4 to 8 shelves making 9 sizes. The screening surfaces have circular holes from $5\frac{1}{4}$ in to $\frac{1}{16}$ inch in diameter. Lips are provided on the screens whic inclined from $\frac{1}{2}$ to $1\frac{1}{2}$ inch per foot to discharge the material.

The rolls used at Cross Creek are corrugated, and do not pointed teeth. It is preferable to increase the number of rolls not to make them adjustable for breaking different sizes. Wh small quantity of coal has to be broken into different sizes co corrugated rolls are used.

Hand-picking is unsatisfactory in a general way, because the can only be picked on the top, a piece of slaty appearance ma moved several times, and the amount of work done by each cannot well be judged. A new form of picking shoot has adopted. The coal is fed along one shoot, and is diverted thr short shoots placed sufficiently far apart to accommodate men pick over the coal, and pass it on to the delivery shoot, which is parallel to the supply shoot.

The jigs are a modification of the Lührig jig.

The automatic slate-picker depends on the fact that, while coal generally breaks into cubical masses, the pieces of slate of the same width and length are much thinner. If placed on edge the slate would accordingly fall through a screen which would retain the coal. The fixed slate-picker consists essentially of a series of cast V-troughs, one side of the V being shorter, and at right angles to the other. The lower half of each trough has a taper slit in the short side, so that anything lying on the long side of the trough may fall through if thin enough, while thicker coal remains and slides from the end of the picker. The lower end of this device is unsupported, like the finger bar screens. The gyrating slate-picker depends on the same principle. A third method of sorting out slate depends on the different sliding capabilities of coal and slate on an inclined shoot; the coal slides fastest and jumps a gap at the lower end, while the slate falls through. At Drifton the slate from the gyrating picker is treated in jigs.

For conveying coal in the building, shoots, elevators, drags, and loading-lips are employed. Spiral, half-round troughs are used to make the shoot continuous when its direction changes abruptly. The bucket elevator is arranged so that the chain travels horizontally for some distance at the top and bottom. The buckets are triangular in cross section, so that they clear themselves at the top when they are travelling horizontally, and the coal has to fall a very short distance on to the discharging shoot, where it is pushed along by the buckets till it is clear. The similar arrangement at the bottom takes up the coal gradually.

The coal is conveyed to the top of the works on a steeply inclined plane in "gunboats," which somewhat resemble a metal-mining skip. The coal is emptied into this from the trams by an automatic tipper, which consists of a simple frame with a toothed rack on its under side. This rack gears with a toothed segment, and the frame tips up and rolls on this segment when the loaded tram is received. A toggle lever arrangement holds the tip, and the weight is placed so that there is an automatic return. An auxiliary truck or "barney," to which the hauling rope is permanently attached, pushes the "gunboat" up the incline. This small truck runs on a narrower gauge, so that it can run through a movable bridge, over which the empty trucks are removed when they descend, into a pit below. The "barney" carries a pivoted frame which, owing to the continued pull on the rope, lifts the of the coal truck when it arrives at the top and discharges it into shoot. In another arrangement the rails are placed so that the tr is automatically tilted.

The author then deals with the structural ironwork in the buildi It is a pin-connected structure, the posts being of cast iron and ties of wrought iron. Most of the large beams are riveted p girders; the smaller are rolled iron. There are three large lat girders. The incline plane is also a pin-connected structure. disposition of the machinery and the specification of the more portant iron members of the structure are given. After this the of material through the building is described.

REFRACTORY MATERIALS.

Plasticity of Clays.—According to Seger,* very refractory clays are not able to stand the chemical action of attacking substances as well as other clays of only medium fire-resisting quality, but of greater plasticity. These latter clays, in consequence of this property, set together quicker into the form of a hard fire-brick-like mass. The author gives examples in proof of this statement.

Kaolin from Breteuil.—The following is an analysis of kaolin from Breteuil.† It is remarkable for the very high percentage of alumina and the total absence of magnesia:—

Al_2O_3.	SiO_2.	Fe_2O_3.	CaO.	MgO.	Na_2O.	K_2O.	Loss on Ignition.
47·80	41·38	trace	0·84	0·00	0·56	0·20	9·30

Kaolin from New South Wales.—The following is an analysis ‡ of kaolin from Shaking Bog, near Tumut, New South Wales:—

SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	K_2O+Na_2O.	H_2O.
44·46	37·85	trace	0·22	trace	1·18	16·29

Analyses of Fire-Clay.—Gaudin § gives the following analyses of fire-clays and quartzite:—

Description.	Stourbridge.	Newcastle.	Saarau.	Quartzite.
Alumina	26·59	27·30	36·30	0·04
Silica	65·65	59·80	43·84	99·44
Ferric oxide	5·71	6·90	0·46	0·45
Alkalies	2·05	6·00	0·42	...
Lime	...	...	...	0·04
Magnesia	...	...	...	trace
Sulphuric anhydride	...	...	...	0·03

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* *Thonindustrie Zeitung*, 1890, No. 14.

† *Chemiker Zeitung; Repertorium*, 1890, p. 72.

‡ *International Exhibition of Mining and Metallurgy, London*, 1890. Official Report on New South Wales Exhibits, p. 85.

§ *Thonindustrie Zeitung*, 1890, No. 37.

Hettenleidelheim Fire-Clay.—According to Dr. Aron,* an average sample of this clay has the following composition :—

Alumina.	Silica.	Ferric Oxide.	Alkalies.
35·05	47·35	2·30	4·80

Occasionally the percentage of alumina reaches 45.

This clay shows no signs of fusion even at the melting point of platinum, and reaches nearly its maximum contraction, 7·3 per cent., at the relatively low temperature of 980° C.

Fire-Resisting Stone from Eisenberg.—This material possesses, according to Professor F. Rhien,† the following percentage composition :—

SiO_2.	Fe_2O_3.	Al_2O_3.	CaO.	MgO.	SO_3.
99·444	0·446	0·040	0·040	traces.	0·028

This material is used largely in the manufacture of fire-bricks.

The Mount Savage Fire-Brick Works.—These works are situated at the foot of the Savage Mountain, 9 miles north of Cumberland, Maryland. The material from which the bricks are manufactured is a fire-clay found in immediate contact with the Cumberland coal-seams. The ordinary process of burning is supplemented by the introduction of gas, by which the bricks are subjected to a heat so intense as to liquefy any less refractory material, and all in the same kiln are burned to a uniform degree.

By an analysis made under the direction of the Massachusetts Institute of Technology, the Mount Savage fire-clay, dried at 212° F., contains :—

Silica	50·457
Alumina	35·904
Ferrous oxide	1·504
Manganese oxide	trace
Lime	0·133
Magnesia	0·018
Water and organic matter	12·744
Total	100·760

No. 1 factory has a drying-floor 100 by 150 feet, and the No. 2 factory 100 by 180 feet. The internal workings of each are an exact counterpart of the other. The clay, as brought in from the yards, is tipped into the grinding-pan, when 4-ton rollers crush it through the perforated bottom of the pan. From this basin an elevator carries it to a bin above the mixer; thence it falls into the mixer, where a stream of water meets it. An endless belt distributes the pasty mass to the moulders, who, after the moulding is completed, place the bricks on the drying-floor. Thence they are taken to the hand-presses and stamped and made perfectly true; then they are wheeled into the kilns. Gas and coal are used in the burning.

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* *Stahl und Eisen*, vol. x. p. 902.

† *Ibid.*, vol. x. p. 902.

There are two large kilns, each over 200 feet in length, to each of which a gas-producer is attached. These kilns are divided off in sections. The gas-producer is mounted on rails and moved from one section to another, so that while section No. 2 is burning, the burned brick may be removed from section No. 1, and at the same time section No. 3 may be filled, and so on. Thus these kilns are being filled, burned, and emptied simultaneously. Their capacity is 500,000 bricks at a filling.*

Preparation of Magnesia for the Basic Process.—If the refractory properties of the magnesia are to be fully utilised the whole of the magnesite must be dead-burnt.† The calcination is difficult, on account of the tendency of the magnesite to splinter and fall to pieces. Recently dolomite has been used instead of magnesite. Two processes of preparing the material are in use, that of Closson and that of Scheibler. In the former process the calcined dolomite is mixed with magnesium chloride, a soluble calcium chloride being formed. This can readily be washed out, leaving the insoluble magnesia. In Scheibler's process the calcined dolomite is treated with dissolved sugar, sugar of lime being formed and magnesia deposited. The solution of sugar of lime is then exposed to the action of carbonic anhydride, calcium carbonate being formed, and the sugar left ready for use again.

The Borrowdale Graphite.—In a paper read before the Geological Society, Mr. J. Postlethwaite ‡ discussed the mode of occurrence and probable origin of the Borrowdale graphite (plumbago). The mineral occurs in veins traversing diabase and diorite, which break through the volcanic series of Borrowdale. Many thousand feet of volcanic rock supervene between the plumbago-bearing rocks and the overlying carbonaceous shales of Silurian age. The author finds similarities between the containing rocks in Borrowdale and the diamond-bearing rocks of South Africa, and considers that the conditions under which the plumbago was formed in the Lake District approached much more closely to those which gave rise to the Kimberley diamonds than to those which originated the plumbago deposits in North America, though there is great dissimilarity in the chemical composition of the intrusive rocks in the two cases, especially with regard to the quantity of magnesia present. He suggests that the molten magma in its upward course passed through a deep-seated stratum of highly carbonaceous material and tore off numerous fragments, the bituminous matter in which became acted upon by heat, a further alteration being subsequently caused by the intrusion of the diorite.

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* *The Pittsburgh Chronicle Telegraph*, October 8, 1890.

† *Glaser's Annalen für Gewerbe- und Bauwesen*, vol. xxxv. p. 139.

‡ *Quarterly Journal of the Geological Society*, vol. xlvi. p. 124.

Graphite-Mining in Austria and Bavaria.—According to T. Andrée,* graphite is met with in almost all the Austrian provinces, the chief deposits occurring in Styria, Lower Austria, Moravia, and Bohemia.

The graphite region of Styria extends from Leoben to St. Lorenzen for a distance of twenty-five miles, with occasional interruptions. Geologists are not yet agreed as to the exact age of these deposits. It is, however, undisputed that they are of more recent formation than those of any other Austrian district. In character and appearance they resemble anthracites. They are, however, true graphites.

The most important and best-known deposit is that of the Kaisersberg at St. Michel, where five parallel beds occur in greyish-black graphite schist. They course in a north-west south-east direction, and dip 70° to 80° to the south-west. They are known for a length of 220 yards, and vary in thickness from a few inches to six yards. Small intercalations of quartz nodules and slate occur, but never of limestone or kaolin. Iron pyrites is very rare. The graphite is of a deep-black colour, with high lustre, is very dry to the touch, and cannot be kneaded together.

In the vicinity of Mautern there are three small mines where the mineral occurs in a similar manner. All these beds are worked by means of adits. The graphite is sorted according to its degree of brittleness. The most brittle variety is No. 1, and the hardest No. 3. The mass of No. 1 is tipped on to a $\frac{5}{8}$-inch screen; the material which falls through is marketable. No. 2 is treated in the same way, but No. 3 is stamped. The proportion of graphite in the Kaisersberg mineral is 88·5 per cent. in No. 1 mineral, 80·7 per cent. in No. 2, and 73·8 per cent. in the marketable product. No concentration takes place. At Kaisersberg all three varieties are mixed, and only one product put on the market, which is a very limited one on account of the great cost of transport. As silica is the main impurity, the graphite is very refractory, and is used for the manufacture of crucibles.

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* *Jernkontorets Annaler*, 1890, Part ii.

In Lower Austria, Moravia, and Bohemia there are numerous graphite deposits, but they are mostly unworked, as the mineral is extremely impure. The graphite chiefly occurs in association with granular limestone in gneiss. It is usually amorphous, and may easily be reduced to powder. In Bohemia laminated varieties are also met with. At Schwarzback, in south-western Bohemia, there are six parallel beds, which have been worked by Prince Schwarzenberg to a depth of 262 feet. The graphite is concentrated and compressed into bricks before being put on the market.

The graphite deposit at Passau, in Bavaria, the only workable one in Germany, has been worked for centuries. The graphite is well adapted for the manufacture of crucibles. It occurs in a felspathic gneiss, in which it partially takes the place of mica, in the form of small greyish-black scales. Besides this variety of graphite, beds of massive amorphous graphite of poor quality are also met with.

The mineral is worked chiefly by peasants in the winter in a primitive manner by means of small shafts. At Kropfmühl systematic working is carried on by Bessel Brothers with the aid of a shaft 105 feet in depth. The thickness of the bed is extremely variable, the maximum being 16 feet. Intercalations of quartz and weathered felspar are of frequent occurrence. Limestone is absent, and iron pyrites occurs only in a finely disseminated form.

The primitive system of concentration adopted yields a very pure product, but is accompanied by a great loss of graphite. The graphite, as brought from the mine, is separated, according to its hardness and purity, into several sorts. The softer varieties are at once ground in an ordinary grinding-mill with horizontal stones, whilst the harder varieties are first crushed in a stamp battery. During the grinding the elastic very thin and soft scales of graphite are deposited parallel to the direction of motion of the millstones, and so preserve their flat form, whilst the hard and brittle masses are converted into fine flour. The ground product then passes over a sieve with fine silk gauze, on which the graphite scales remain, whilst the fine flour passes throug This concentration is done in the dry, and the waste always contai graphite. Good average analyses show that the best raw mine contains 53·8 per cent. of graphite, the dressed mineral 89·2 per cen and waste material 36·8 to 22·3 per cent. The purified graphite used exclusively for the manufacture of crucibles.

The graphite district of South Bohemia is described by A. Pallausch It extends, in the vicinity of Przinitz and Eggetschlag, over an ar 14 miles long and 10 miles wide. The graphite occurs in the form lenticular masses embedded in gneiss. Mining was commenced 1767, and continued in a primitive manner until 1811, when Prin Schwartzenberg began mining on a large scale. The largest of h mines works the Florian bed, which has been explored for a leng of 600 yards by means of four shafts varying in depth from 144 262 feet.

The soft graphite is brought from the mine in three classes. T two best classes are first hand-picked, and then dried on a steam-heat boiler-plate, and packed in barrels ready for the market. The thir class mineral and the hard graphite are crushed in a roller-mill wi excess of water, and the resulting mud is passed through six separati tanks, and thence through eighteen depositing tanks until the graphi slime attains a given height. The slime is then transferred to a stirri tank, and forced by pumps into large filter-presses, which yield tabul cakes of graphite containing 20 per cent. of moisture. These are dri and sold. The selling prices of the pure graphite varies from £1, 1 to £20 per ton, and that of the refined product from 16s. to per ton. The production at Prince Schwarzenberg's works in 18 amounted to 6753½ tons, valued at £17,850.

Graphite-Mines of Ceylon.—According to J. Walther,† in t graphite-mine a mile and a half from Kaltura, in Ceylon, the graph is met with in a series of veins in gneiss which has become convert to a depth of 12 yards, into a mass resembling laterite. The thick vein is 6 inches to 1 foot in breadth. With regard to the gneiss the veins, the author is of opinion that they must not be regarded dislocated seams or beds originally deposited horizontally, but th they are true veins whose eruptive nature has been disproved Sandberger's researches. It is also highly improbable that the carb has been deposited from solution, seeing that the edges of the vein are quite free from graphite. Moreover, no liquid possessing the power of dissolving carbon is known. It is therefore probable that the graphite was derived from carburetted vapours. The view is supported by the facts that hydrocarbons are widely distributed throughout the earth, and that sublimed carbon has been met with in gasworks. The minerals found enclosed in the graphite might be partly derived from the gneiss, and partly subsequent infiltrations. The author does not insist that all graphite has been formed in this way. It, however, appears to him that in this instance the ordinary theory that the mineral is the result of the alteration of cellulose is out of the question. In other instances closer investigation is desirable.

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* *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, 1889, p. 95.

† *Zeitschrift der deutschen geologischen Gesellschaft*, vol. xli. pp. 359–364.

PRODUCTION OF PIG IRON.

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I.—*BLAST FURNACE PRACTICE.*

Chemical Reactions in the Blast Furnace.—F. Brabant [*] discusses the loss of heat which takes place in the blast furnace by the reduction of carbonic anhydride to carbonic oxide, a loss which he places at 0·618 part of carbon for every 1 part of the reduced carbonic anhydride. The ideal combustion of the carbon in the blast furnace, involving no after reduction of the carbonic anhydride formed, is most closely approached in charcoal furnaces, owing, the author believes, to the direction taken by the currents of gas rising through the furnace, being such as is not attainable in a coke blast furnace.

The unequal character of the temperature in different parts of the several layers leads to the loss of carbon being the greater the hotter are the furnace gases, a very small variation in such temperature having a considerable effect.

A Blast Furnace Charge.—P. Gredt [†] states that at No. 3 furnace of the ironworks belonging to Messrs. Metz & Co., at Esch-on-the Alzette, Luxemburg, the following minette ores are treated :—

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[*] *Revue Universelle des Mines*, vol. ix. pp. 133-150.

[†] *Stahl und Eisen*, vol. x. p. 598.

Composition.	Red.	Grey.	Brown.	Russange.	Kidney.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica	7·98	8·30	13·00	16·00	7·42
Alumina	5·56	7·00	6·00	5·00	5·28
Lime	13·77	15·00	6·30	7·00	23·75
Magnesia	0·53	0·50	0·90	1·00	0·50
Ferric oxide	51·14	48·57	58·57	54·29	38·73
$H_2O + CO_2$	21·02 *	20·63	15·23	16·71	24·32
Totals	100·00	100·00	100·00	100·00	100·00

The smelting mixture consisted of:—

Red.	Grey.	Brown.	Russange.	Kidney.
21·0	14·0	53·5	3·5	8·0

Forty-four charges were passed through daily, each charge weighing 6·6 tons, or a total daily charge of 290·4 tons. This quantity of ore evolved on heating in the furnace 46·118 tons of water and carbonic anhydride.

The charge of coke weighed 2·1 tons, and in a day 92·4 tons were charged into the furnace. This coke contained 7·88 per cent. of ash and 7·82 per cent. of moisture.

No. 2 blast furnace treated a smelting charge consisting of 44 per cent. grey minette, 36 per cent. of minette from Belvaux, and 20 per cent. of kidney ore. The composition of these ores was as follows:—

Composition.	Grey.	Belvaux.	Kidney.
	Per Cent.	Per Cent.	Per Cent.
Silica	8·68	14·12	8·00
Alumina	4·01	5·53	5·28
Lime	17·94	8·16	23·75
Magnesia	0·47	0·70	0·50
Ferric oxide	46·00	56·14	38·57
$H_2O + CO_2$	22·90	15·35	23·90
Totals	100·00	100·00	100·00

The daily charge consisted of 214·6 tons of ore, containing 43·74 tons of moisture and carbonic anhydride, and 39·9 tons of coke of the same composition as that charged into No. 3 furnace.

The air-blast used in smelting this charge weighed 442·79 tons.

* 11·02 in the original.

Large Charcoal Blast Furnace.—The largest charcoal blast furnace on the Continent of Europe has recently been blown-in at Vayda-Hunyad, Hungary. Its annual capacity is about 15,000 tons.

The ore to be smelted is brought from the mines direct to the furnace by an overhead wire-ropeway 35·4 miles in length. The Bessemer iron made is sold to the Diosgyör Steelworks for conversion into railway and bridge construction materials.*

Cylindrical Charcoal Blast Furnace.—P. Zetzsche † gives the dimensions of the almost cylindrical charcoal blast furnaces erected at the Bjelorzk Ironworks in the Ural. The dimensions are as follows: Height, 46 feet 9 inches; diameter at boshes and throat, 5 feet; diameter at hearth, 3 feet; capacity, 823 cubic feet.

The daily production, using a mixture of magnetite and brown iron ore, is 10 tons, the charcoal used amounting to 1·181 ton for every ton of pig iron. The blast is heated to a temperature of 225° C.

Modern Blast Furnace Construction.—Mr. J. L. White contributes a series of articles on this subject to the *Iron Age.*‡ He deals in the first place with the selection of a site for the plant, pointing out that great care should be taken to have an adequate tipping ground for the slag, and for this reason a site on the sea-shore or on that of a large lake is distinctly advantageous, as any situation necessitating a long haul for the slag involves a permanent working charge which ought to be avoided. The plant should not be cramped for space, and the lines of rails laid down should be of easy gradient and free from sharp curves. The foundation, too, is an all-important matter, and there must be a good water-supply.

The author then considers the following questions relating to the furnace plant to be erected: (1) The stack or shell of the furnace proper; (2) the downcomer or pipe conveying the gas to the boilers and hot-blast stoves; (3) the boilers to provide steam for running the plant; (4) the blowing engines and house; (5) the hoist for stock; (6) the stock-house, to store, keep dry, sort, and weigh materials in; (7) the cast-house, to protect the pig bed from the weather; (8) the hot blast stoves; (9) the gas flues leading from the downcomer to the boilers and stoves; (10) the chimney for creating a draught and carrying off waste gases; (11) the water tank; and (12) the pumps and electric light plant.

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* *Stahl und Eisen*, vol. x. p. 900.

† *Ibid.*, p. 853, with illustrations.

‡ Vol. xlvi. pp. 406, 445, &c.

A design for a works is given, together with drawings of the plant to be erected, the whole question being considered at great length.

Ironworks in Bosnia.—An ironworks is about to be erected in the neighbourhood of the ore deposits at Barcs, in Bosnia. Hitherto there has been no blast furnace in this district, the iron ore being smelted in small bloomery furnaces, the total annual production of which was about 500 tons. At the new blast furnace charcoal will be used as fuel.*

The Monongahela Blast Furnaces.—The Monongahela Ironworks is situated at M'Keesport, Pennsylvania. The plant has been recently erected, and a plan and description of the works are published in the *Iron Age*.† The blast furnaces are of the following dimensions: Height, 80 feet; diameter at the boshes, 20 feet. The columns are of cast iron 2 inches in thickness, with an average diameter of 25 inches and a total height of 22 feet 9 inches. The base-plate under the columns is made up of cast iron sections, held together by wrought iron links shrunk in position; the top of the plate being 3 feet below the furnace level. The mantle-plate is of novel construction, the intention being to prevent warping. It is composed of three I beams bent to circles, the centre I beam 20 inches deep, resting in a recess in the top of the columns, with two 15-inch I beams bearing on and bolted to the top flanges of the columns. The beams are securely held together by cast iron distance pieces and bolts, while the tops of the flanges of the beams are riveted wrought iron cover-plates. Spaced intermediately between the columns are gusset-plates, extending from the cover-plates of the mantle to the top of the first sheet in the furnace casing. This construction affords great stiffness and resistance to warping.

Extending downward from the mantle, and riveted to it, is the bosh casing. Round the base of this casing is riveted a Z bar, which acts as a water-trough in collecting the water discharged from the spray-pipe at the top of the boshes, and conducting it to the waste-water pipe. A similar bar is provided at the base of the furnace cas proper, in order to gather the water which runs down the furnace, thus prevent dripping during a rain-storm.

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* *Oesterreichische-Ungarische Montan und Metallindustrie Zeitung;* through *Stahl und Eisen*, vol. x. p. 576.

† Vol. xlvi. pp. 212-216; five illustrations.

The furnace casing is composed of iron plates ranging in thickn from ½ inch to $\frac{5}{16}$ inch. To the top are riveted cast iron brack inside and out; the former for the support of the bell, &c., and latter for the support of the platform outside the casing. The bell hopper are of the usual construction, but the apparatus for work it is novel, the purpose being to secure a strictly vertical motion raising and lowering the bell. The steam cylinder for working bell is provided with a steam cushion, which avoids the possibility "hammer" on the cylinder-head lowering the bell.

The inwall of the furnace is 36 inches in thickness, and the bos 31½ inches, the hearth tapering from 31½ inches to 36 inches. Arou the brickwork of the latter a wrought steel casing with expans joints is provided, bolted to a cast iron water-cooled draw-plate front. For cooling the hearth a spray-pipe is provided at the to the hearth-jacket, the water passing thence to a circular pit round base of the hearth.

The boshes are cooled by four rows of bronze bosh-cooling pla The tuyere and slag coolers are also constructed of bronze. furnace bridge rests at one end on the hoist tower, and at the ot on the furnace casing, the whole being securely riveted in posit The bridge is covered with a roof extending from the shed at the of the hoist tower to the canopy over the top of the furnace. In centre of this canopy, and directly over the hopper, is provided a fl with conical mouthpiece for carrying away escaping gases. A ve lator is also provided in the roof covering the bridge.

The hoist tower is composed of six wrought-iron columns, prop held together by studs and tie rods. The downcomers are lined 4½ inches of fire-brick, and communicate with dust-catchers of n design. Cowper stoves are used, each 79 feet 8½ inches high and feet in diameter.

New American Blast Furnace.—The first blast furnace is b erected at Cardiff, Tennessee. Its dimensions are to be as follows Height, 75 feet; diameter at the boshes, 16 feet. There will be t fire-brick stoves, each 19 feet in diameter and 70 feet high. T will have a heating capacity of 22,000 cubic feet of air, the temp ture of the blast being 1500° F. The blowing-engines will be in number, with blast cylinders 7 feet in diameter and a stroke of 5 feet. They will be of 900 horse-power.*

New Virginia Blast Furnaces.—The following are the dimensions of some new furnaces recently erected, or still in course of erection, in Virginia:—

Locality.	Height.	Diameter at Boshes.	Daily Capacity.
	Feet.	Feet.	Tons.
Roanoke	82	17	150
Graham	70	16	100–125
Salem	75	14½	100–120
Radford	75	18½	...

The Salem furnace has a 9-foot hearth, and is provided with seven tuyeres. The blast is heated by three Whitwell stoves, each 60 feet in height and 18 feet in diameter, and is supplied with two blowing-engines, having cylinders 38 and 84 inches, and a 4-foot stroke.†

The Oregon Blast Furnace, Oswego.—The blast furnace belonging to the Oregon Iron and Steel Company at Oswego, Oregon, was blown-in in 1888. It is 13 feet wide at the boshes and 60 feet high, and is provided with six 5½-inch tuyeres. The bosh walls are protected by water blocks, and the shaft of the furnace is lined with fire-brick 2 feet in thickness, with a back wall of red brick 18 inches thick. The downcomer gas flue, from the furnace to the stoves and boilers, is of wrought iron, 6½ feet in diameter, lined with fire-brick. For heating the blast there are three fire-brick stoves with wrought iron shells, 15 feet in diameter and 75 feet high, with conical tops. The blowing-engine is of the Weimer type, having a total weight of 100 tons and a horse-power of 800. The capacity of the blow is 12,000 cubic feet of air per minute, with 10 lbs. pressure to the square inch. The daily capacity is about 50 tons of pig iron, charcoal being used as fuel.‡

Blast Furnace Record.—No. 3 blast furnace of the Phœnix Works at Berge-Borbeck has recently been blown-out after what is claimed to be the longest blast on record on one lining. It was blown-in on March 31, 1873, and was in blast until July 15, 1890. During this period of over seventeen years it made 355,236 tons of pig iron. The dimensions are: Height, 49 feet 5 inches; diameter at the boshes, 16 feet. Until within a year of the termination of the blast iron-pipe stoves were used; since then two Cowper stoves have been erected, and the furnace has made 80 tons of pig iron a day, the capacity of the furnace being then about 71 cubic feet for every ton of iron made.[*]

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* *Iron Age*, vol. xlvi. p. 179.

† *Ibid.*, p. 480.

‡ *Ibid.*, p. 58.

A Charcoal Blast Furnace Record.—The Hinkle blast furnace[†] of Ashland, Wisconsin, made, according to Mr. R. Hunt,[‡] 1009 tons of pig iron during the seven days ending October 4, 1890, the daily output varying from 141 to 150 tons. The materials charged included:—

	Tons.
Charcoal	814
Ore	1811
Limestone	80

The yield of ore was 56·4 per cent., and the number of charges amounted to 1764.

A Small Blast Furnace.—A small cupola type of blast furnace, designed for the smelting of iron ore in Mexico, is illustrated in *Industries*.[§] It is capable of reducing from 5 to 10 tons daily. Air for the blast is led through an iron pipe, placed centrally in the downcomer. The combustible gas from the latter is taken to a hot-blast stove, in which the air-blast is additionally heated in vertical iron pipes. Openings are provided in the stove to admit air for combustion. In the centre of the heating pipes spiral steel bands are placed to increase the travel of the air, and to induce it to flow to the sides of the pipes.

Smelting Titaniferous Iron Ore.—Mr. A. J. Rossi[||] fully discusses the question of the smelting of titaniferous iron ores. American ironmasters have generally thought that mixtures containing more than

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[*] *Stahl und Eisen*, vol. x. p. 742.

[†] See *Journal of the Iron and Steel Institute*, 1890, No. I. p. 285.

[‡] *Iron Age*, vol. xlvi. p. 630.

[§] Vol. ix. p. 152.

[||] *Journal of the American Chemical Society*, 1890, p. 91.

1·25 per cent. of titanium could not be successfully used. When present in greater quantities this element has a tendency to make the slag pasty, and to cause deposits in the furnace if it be not caused to pass into the slag. Owing to this, many titaniferous deposits have not been worked, although the ore is generally very free from phosphorus, and especially suitable for Bessemer iron. Ores containing 5 to 10 per cent. of titanium oxide have, however, been smelted in Sweden and Norway without admixture in charcoal furnaces. Even when the ores contained 15 to 20 per cent. of the oxide, they have been smelted alone or by the aid of fluxes. A Norway ore, with as much as 40 per cent. of titanium oxide and only 36 per cent. of iron, has been smelted successfully in England, although a large amount of fuel was required.

The choice of fluxes entirely determines the successful treatment of these ores. Certain natural compounds of titanium, such as sphene, calcium silico-titanate, and keilhanite, are perfectly fusible in the blast furnace, and the composition of the slag should be made to approximate to these compounds. The following analyses show the composition of one ore used in Norway, the composition of the slag, and of average sphene for comparison:—

Description.	Ore.	Slag.	Sphene.
Silica	5·70	27·83	31·78
Titanic anhydride	39·20	36·18	40·00
Lime	...	24·36	24·59
Ferrous oxide	30·00	1·86	2·00
Ferric oxide	18·59		
Alumina	2·89	9·18	2·00
Magnesia	...	0·60	2·00
Manganese oxide	0·60	...	...
Iron	36·3	...	...

All the titanium is caused to pass into the slag with the exception of 1 or 2 per cent. left in the pig iron, and, thus, no scaffolding from titaniferous deposits can arise.

The Value of Self-Fluxing Ores.—Mr. S. A. Richards * discusses the truth of the statement that an ore poor in iron cannot be carried for any distance with a view to competing with an ore of higher grade. He proceeds to show the fallacy in many cases of this belief, and he gives the following analyses of United States iron ores within, or nearly within, the Bessemer limit as to phosphorus:—

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* *Iron Age*, vol. xlvi. p. 182.

No.	Iron.	Manganese.	Silica.	Alumina.	Lime.	Magnesia.
1	60·37	0·54	7·10	2·95	0·25	0·19
2	61·10	0·96	7·80	0·43	0·36	0·14
3	60·17	0·92	7·85	2·46	0·25	0·11
4	58·00	0·41	14·17	1·43	0·34	0·29
5	58·10	0·39	14·10	1·00	0·45	0·07
6	61·00	0·11	9·00	1·10	0·75	1·06
7	56·80	0·04	9·95	2·26	0·45	0·97
8	54·46	0·27	17·06	0·11	1·59	0·99
9	54·20	0·75	2·80	0·95	7·05	3·61

Calculations based on the composition of the gangue in the foregoing ores, deducting moisture in each case, show that the quantity of material required to produce a ton of pig iron will be as follows:—

No.	Ore.	Lime.	Coke.
	Lbs.	Lbs.	Lbs.
1	3,930	1,180	2,320
2	3,870	1,190	2,290
3	3,930	1,220	2,330
4	4,070	2,030	2,640
5	4,070	2,030	2,640
6	3,860	1,350	2,340
7	4,150	1,650	2,570
8	4,300	2,900	3,000
9	4,190	...	2,200

The price in the season of 1890 of ore No. 9 has been 1·90 dollar at the mines, or 3½ cents per unit. Calculating the other ores on this basis, the cost per ton of ore should be as follows at the points named:—

No.	Chicago.	Mahoning and Shenango Valleys.
	Dollars.	Dollars.
1	3·85	4·75
2	3·90	4·80
3	3·85	4·75
4	3·80	4·70
5	3·80	4·70
6	3·90	4·80
7	3·75	4·65
8	3·65	4·55
9	3·65	4·55

Estimating the cost of coke at Chicago at 5 dollars per ton, and in the valleys at 3 dollars, while the limestone is assumed to be 70 cents at all points, the cost of material per ton of pig iron would be as follows:—

No.	Chicago.	The Valleys.
	Dollars.	Dollars.
1	12·96	12·22
2	12·88	12·23
3	12·98	12·25
4	14·20	13·21
5	14·20	13·21
6	18·05	12·35
7	13·94	13·05
8	15·53	14·66
9	12·32	11·81

From these calculations it will be seen that, notwithstanding the comparative leanness of No. 9, pig iron will be made from it at lower cost than from the much richer ores. Nos. 4, 5, and 8, being high in silica, are the dearest ores in the series selected for illustration.

For Bessemer purposes, the author points out, self-fluxing ores can rarely be used; but for the basic open-hearth, mill, and foundry irons, such as those referred to in the comparison given above, they are much more economical.

Handling Pig Iron.—A method of removing pig iron from the pig-beds has been designed by Mr. J. L. Boyer, and is intended to dispense with manual labour. The apparatus consists of two grappling devices, of four hooks each, suspended from trolleys running on a traveller which spans all the pig-beds. The grapples are driven by steam pistons, and are worked by a man and a boy. They take up several pigs at once, and can remove the iron as soon as it is cool enough to retain its shape.*

Magnet for Blast Furnace Use.—At the Pittsburgh Exhibition, Messrs. Hughes and Gawthrop showed an electro-magnet designed for lifting pig iron from the pig-bed in the casting-house. It had a lifting capacity of 7200 lbs., and in shape it resembled a bell with vertical sides, standing 20 inches in height and measuring 24 inches across the base. The thickness of the sides was 3 inches. Within the bell, and flush with it at the base, was a large coil, forming a powerful electro-magnet. The magnet can be raised or lowered by a crane, and the load can be dropped by simply shutting off the current.†

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* *The Engineering and Mining Journal*, vol. xlix. p. 702.

† *Ibid.*, vol. l. p. 576.

Repairing a Blast Furnace.—W. M. Stein * gives an account of the method of repairing adopted in a case in which that portion of the brickwork at the top of a blast furnace against which the charge rolled on falling from the cone had become almost destroyed. The furnace was at the time in full blast, but when it had been decided to commence the repairs no ore was charged, but coke alone. After tapping off the greater part of the iron reduced from the charge of ore already in the furnace, the blast was shut off, and the tuyere and other openings carefully closed. Three hours after this had been effected the removal of the cone was commenced. It was then found that the furnace was filled to within about 25 feet of the cone. A layer of small coke 3·5 feet in thickness was then spread over the surface of the charge, and on this again 5 tons of ore fines. The furnace was then allowed to stand until the next day, when another 5 tons of ore was charged in, the intention being to separate the lower and hot portion of the furnace from the upper portion to be repaired. An 18-inch hole was next bored through the ore covering, and a pipe placed above this to take off any gas that might form.

The repairs were then effected, although the temperature of the upper part of the furnace was still so high that the workmen employed had to be changed every few minutes.

Blast Furnace Gases.—P. Gredt † describes the utilisation of the gases escaping from the blast furnaces at the Metz Works at Esch, Luxemburg.

The gas escapes at a mean temperature of 98° C. Analyses showed it to contain :—

Description.	Per Cent. Volume.	Per Cent. Weight.
Carbonic anhydride . . .	13·80	18·04
Oxygen	0·60	0·57
Carbonic oxide . . .	23·50	19·54
Marsh gas	2·20	1·05
Hydrogen	0·13	0·008
Nitrogen	59·77	49·85
Water	...	10·29
Dust	...	0·66
Totals . .	100·00	100·008

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* *Metall- und Eisen-Zeitung*, through *Stahl und Eisen*, vol. x. p. 465.

† *Stahl und Eisen*, vol. x. pp. 591–602.

The dust contained :—

Description.	Per Cent.	Specific Heat.
SiO_2	10·10	0·1913
C	13·74	0·2040
Fe_2O_3	29·50	0·1670
Mn_3O_4	0·50	0·1671
SO_3	0·58	0·1544 (SO_2)
P_2O_5	1·63	0·1800 (?)
Al_2O_3	10·73	0·1276
ZnO	7·47	0·1248
CaO	8·20	0·1800
MgO	0·79	0·2439
K_2O	0·86	0·1710 (KCl)
Na_2O	1·31	0·2130 (NaCl)

The average specific heat of the dust is thus about 0·1700, its specific gravity being 3·59.

The furnace from which this gas escaped was closed, and was provided with the Hoff system of gas collection. The quantity of gas produced daily amounts to 24,910,155 cubic feet, or, by weight, 1060·5 tons. The heat carried off by this quanity of gas is equivalent to the complete combustion of 3·44 tons of carbon. 0·1 ton of this gas, when completely burnt, will yield 63,370 calories, the calorific intensity being 1525° C.

Full details of calculation are given, showing the absolute loss of heat from the escaping gases, both at the furnace, dust-catcher, &c., boilers, and hot-blast stoves.

Similar details are given relative to other blast furnaces, differently arranged.

The Purification of Blast Furnace Gas.—F. W. Lührmann[*] observes that the "Cyclone" dust-collector has been in use in Germany for some time past. The gas from which the dust is to be deposited is subjected in this machine to a rapid centrifugal motion. The effect of this is to throw the dust against the casing of the machine, whence it falls through a hole in the inverted conical base, the gas passing out at the top. The machine gives good results, is simple in construction, and needs no watching.

Improved Cowper Stove.—F. W. Lührmann[†] describes a modified form of the Cowper hot-blast stove. This modification has a circular combustion chamber surrounding a central chamber filled with fire-brick in the ordinary manner. Various advantages are claimed for the improved form of oven, both as to its general arrangement, improved gas circulation, and increased heat absorption.

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[*] *Stahl und Eisen*, vol. x. p. 821.

[†] *Ibid.*, vol. x. p. 862, with illustrations.

The Cowper-Kennedy Hot-Blast Stove.—Drawings of a slightly modified form of this stove appear in the *Iron Age.** The flues are 9 inches in diameter, and have no vertical joints. The horizontal joints are at distances of 12 inches.

Arrangement of the Brickwork in Hot-Blast Stoves.—F. W. Lührmann † discusses the modified forms of brickwork adopted in the recent modifications of the Cowper and Whitwell stoves.

In the Cowper stove the bricks were at first arranged loosely, without any binding material, exactly as in the older forms of Siemens regenerator chambers. A slightly more recent arrangement consisted in placing the bricks in rows, with every other brick slightly projecting. Vertical channels were thus formed between the bricks, and it was thought that by causing the bricks to project in the manner indicated, a larger heating surface was obtained. Such an arrangement was in use within recent years at Monceau-sur-Sambre.

Such methods of brick arrangement did not, however, admit of the stoves being cleaned; and as the necessity for this became better understood, various methods of brick arrangement were discovered which admitted of the stoves being cleaned by the aid of powder.

As early as 1875, an arrangement came into use in which the bricks were placed in such a manner as to form a large number of vertical flues, almost square in section. By this method the walls of the flues were as free from obstruction as it was possible to effect with bricks unprovided with binding material. The heating surface was, however, small. The author then proceeds to discuss, by the aid of sketches, the more modern arrangements that have since been introduced.

The improvements that have gradually been introduced in the Whitwell system of brick arrangement are treated by the author in a similar manner.

In tabular form are arranged the details showing the comparative efficiency of the various methods of arrangement, it being shown that the Whitwell system is far less efficacious than that of Cowper.

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* Vol. xlvi. p. 43.

† *Stahl und Eisen*, vol. x. pp. 766–771.

The Cost of Production of Pig Iron.—Mr. C. D. Wright, United States Commissioner of Labour, has recently issued the returns of a large number of reports relating to the cost of production of pig iron, and these have been tabulated by the *Iron Age.** As regards charcoal pig iron, the cost per ton varies from 10¼ dollars to rather more than 23 dollars. The following table shows the cost of furnaces using as fuel either anthracite or a mixture of anthracite and coke—about 3 parts anthracite to 1 part coke:—

The Cost of Anthracite Pig Iron (Dollars per Ton).

Items of Cost.	No. 1.—Bessemer.	No. 2.—Bessemer.	No. 3.—Special Bessemer.	No. 4.—Foundry.	No. 5.—Foundry.	No. 6.—Foundry.	No. 7.—Grey Forge.	No. 8.—Run of Furnace.
Days run	365	184	257	167	365	234	181	252
Product	43,800	22,080	18,121	8,297	29,390	11,467	22,931	8,489
Product per day	120	120	71	50	81	49	63 (127)	34
Tons per ton of product—								
Ore	1·820	1·820	1·655	2·447	2·373	2·143	1·509	1·530
Cinder, scrap, &c.	...	...	...	...	...	...	·493	·834
Limestone, &c.	0·488	0·487	0·403	0·587	0·690	0·408	0·576	0·744
Coke, &c.	0·446	0·446	0·359	0·893	0·924	1·093	0·302	...
Coal, &c.	0·500	0·500	0·922	0·650	0·425	0·408	1·086	2·318
Cost of materials per ton—								
Ore	4·950	5·500	5·250	1·886	1·550	2·688	5·854	3·645
Cinder, scrap, &c.	...	...	...	...	...	...	1·572	1·300
Limestone	1·008	1·120	0·900	0·800	0·750	1·000	0·850	0·896
Coke	3·920	4·872	3·577	4·368	5·410	3·920	4·480	...
Coal	3·450	3·500	3·450	3·500	3·598	3·500	3·000	1·638
Cost of materials per ton of pig iron—								
Ore	9·009	10·010	8·692	4·615	3·680	5·759	8·835	5·578
Cinder, scrap, &c.	...	...	...	...	...	...	0·775	1·083
Limestone	0·491	0·545	0·363	0·469	0·517	0·408	0·489	0·667
Coke	1·750	2·175	1·283	3·900	4·997	4·285	1·354	...
Coal	1·725	1·750	3·179	2·276	1·529	1·428	3·259	3·797
Total cost of materials	12·975	14·480	13·517	11·260	10·723	11·880	14·712	11·125
Labour	1·250	1·250	1·380	2·069	1·983	1·738	1·300	1·250
Officials and clerks	0·091	0·091	...	0·464	0·238	0·442	0·274	0·441
Supplies and repairs	0·500	0·500	0·500	0·304	0·624	0·498	0·645	0·321
Taxes	0·028	0·027	...	0·024	0·023	0·049	0·022	0·070
Total cost	14·844	16·348	15·397	14·121	13·591	14·607	16·953	13·207

The cost of production of coke Bessemer pig iron in the northern portion of the Union will be seen from the following table:—

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* Vol. xlvi. pp. 93-95.

The Cost of Coke Bessemer Pig Iron (Dollars per Ton).

Items of Cost.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Days run	297	171	338	344	288	205	310	216
Product	21,074	25,303	24,741	84,620	32,870	72,884	30,000	25,715
Product per day	71	148	73	123	114	178	97	119
Tons per ton of product—								
Ore	1·614	1·380	1·474	1·723	1·597	1·646	1·600	1·513
Cinder, scrap, &c.	0·062	0·116	0·042	...	0·136	0·014	...	0·146
Limestone	0·332	0·320	0·391	0·490	0·600	0·343	0·534	0·581
Coke	0·978	0·879	1·195	1·273	1·127	0·986	1·101	1·458
Coal	0·308	...	...	...	0·057	...	0·089	...
Cost of materials per ton—								
Ore	5·300	6·089	6·050	5·466	5·626	5·719	7·000	6·384
Cinder, scrap, &c.	2·850	5·998	3·250	...	2·469	3·800	...	2·278
Limestone	0·850	1·006	1·042	0·784	1·069	1·008	0·750	1·081
Coke	3·136	2·922	2·689	2·688	2·979	3·640	3·360	2·910
Coal	1·456	...	...	...	1·488	...	1·120	...
Cost of materials per ton of pig iron—								
Ore	8·556	8·404	8·919	9·412	8·984	9·412	11·200	9·662
Cinder, scrap, &c.	0·177	0·697	0·136	...	0·336	0·052	...	0·332
Limestone	0·282	0·322	0·407	0·384	0·623	0·346	0·400	0·627
Coke	3·067	2·568	3·214	3·424	3·358	3·589	3·700	3·515
Coal	0·448	...	...	...	0·085	...	0·100	...
Total cost of materials	12·530	11·991	12·676	13·220	13·386	13·399	15·400	14·136
Labour	1·575	0·975	1·147	1·155	1·490	1·440	1·500	1·642
Officials and clerks	0·124	0·134	0·097	0·178	0·136	0·137	0·317	0·190
Supplies and repairs	0·240	0·403	0·170	0·500	0·484	0·250	0·550	0·793
Taxes	0·010	0·081	0·061	0·023	0·039	0·055	0·019	0·050
Total cost	14·479	13·584	14·151	15·076	15·535	15·281	17·786	16·811

Similar details are given of the cost of production of Bessemer pig iron made with coke, or with a mixture of coke and bituminous coal. The figures relate to other works. They do not, however, vary greatly from those given in the above table. Indeed, it will be seen on reference to abstracts which have previously been published in this Journal,* that the cost of production as given in the accompanying tables is in marked accord with statements previously published.

The cost of pig iron in the Southern States of the Union is considerably less, as the following table shows, but the furnaces are more distant from a market, and the cost of transport is consequently higher:—

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* *Journal of the Iron and Steel Institute*, 1889, No. I. p. 313; No. II. p. 515; 1890, No. I. p. 288.

Cost of Southern Pig Iron (Dollars per Ton).

Items of Cost.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.
Days run	283	286	344	365	371	290	106	365
Product	39,028	35,036	35,158	41,272	19,323	23,486	10,353	62,561
Product per day	69	61	102	113	52	81	98	86
Tons per ton of product—								
Ore	2·414	2·308	2·128	1·964	2·006	2·167	2·110	2·244
Cinder, scrap, &c.	0·010	...	...	...	0·100	0·090	...	...
Limestone	0·450	0·733	0·604	1·044	0·925	0·764	0·376	0·520
Coke	1·828	1·563	1·150	1·403	1·793	1·331	1·358	1·649
Cost of materials per ton—								
Ore	0·647	0·918	1·570	0·841	1·327	1·194	1·432	0·865
Cinder, scrap, &c.	0·685	...	...	...	1·000	1·098	...	...
Limestone	0·906	0·647	0·605	0·755	0·698	0·520	0·840	0·623
Coke	2·843	2·916	3·998	2·545	2·622	3·360	3·731	2·573
Cost of materials per ton of pig iron—								
Ore	1·561	2·165	3·340	1·652	2·662	2·587	3·021	1·960
Cinder, scrap, &c.	0·007	...	...	...	0·101	0·099	...	...
Limestone	0·408	0·477	0·365	0·789	0·646	0·397	0·315	0·324
Coke	5·197	4·560	4·600	3·572	4·701	4·471	5·068	4·243
Total cost of materials	7·173	7·202	8·305	6·013	8·110	7·554	8·404	6·527
Labour	1·816	2·608	1·964	1·663	1·641	1·835	1·873	1·737
Officials and clerks	0·056	0·196	0·173	0·420	0·456	0·178	0·145	0·156
Supplies and repairs	0·555	0·175	0·837	0·400	1·489	0·283	0·413	0·703
Taxes	0·034	0·086	0·031	0·057	0·083	0·031	0·031	0·038
Total cost	9·634	10·267	11·310	8·553	11·779	9·881	10·866	9·161

For the purpose of comparison, the following details relating to the cost of production of Bessemer pig iron at certain works in the United Kingdom are also given:—

Cost of English Bessemer Pig Iron.

Nov. 1, 1888, to Oct. 31, 1889.

Days running	363
Total product, tons	62,929
Daily product, tons	87
Cost of materials per ton, dollars:—	
Ore	3·384
Cinder, scrap	...
Limestone	0·793
Coke	2·689
Coal	2·432
Cost per ton, dollars:—	
Ore	6·387
Cinder, scrap	...
Limestone	0·264
Coke	2·555
Coal	0·030
Total materials	9·236
Labour	0·710
Officials and clerks	0·054
Supplies and repairs	0·212
Taxes	0·032
Total cost	10·244

E. S. Hunter publishes the following calculations of the cost of producing a ton of Bessemer pig iron at Lynchburg, Virginia:[*]—

	Dollars.
Value of ore for 1 ton of iron	7·00
Coke	3·00
Limestone	0·40
Incidental and management	0·25
Labour	1·25
Repairs	0·60
Total	12·50

II.—*CHEMICAL COMPOSITION OF PIG IRON.*

Analyses of Pig Iron.—The following are analyses given by N. Kjellberg[†] of various varieties of pig iron:—

	Carbon.	Silicon.	Phosphorus.	Sulphur.	Copper.	Manganese.
White forge iron	3·4 to 3·8	0·19	0·42	0·07	0·14	1·63
Grey forge iron	...	0·72	0·31	0·04	0·08	2·37
Grey forge iron	2·78	1·18	0·43	...	...	2·28
Grey forge iron	3·10	2·57	0·51	...	...	2·71
Basic pig iron	3·5 to 4	0·3 to 0·4	2·70	0·04	...	0·08
Pig iron, Loire, France	3·50	0·3 to 1·0	0·40	0·05	...	1 to 3
Pig iron, Loire, France	3·00	0·5	0·07	0·03	...	2·00
Low phosphorus, Hungary	4·00	1·5 to 2	0·08	0·04	0·4	2·5 to 3·5
Low phosphorus, Hungary	3·00	2·10	0·06	0·015	trace	2·74
Schwechat (Styria) coke	4·42	1·35	0·11	0·025	...	4·16
Schwechat (Styria) coke	4·05	1·77	0·13	0·017	...	3·96
Schwechat (Styria) coke	3·90	2·11	0·12	0·021	...	4·56
Hieflau (Styria) coke	3·88	0·35	0·06	0·63	...	2·68
Hieflau (Styria) coke	3·48	0·56	0·09	0·03	...	3·31

Dr. E. Prziwoznik[‡] has analysed spiegeleisen from Eisenerz, Austria, with the following results:—

Carbon.	Silicon.	Phosphorus.	Sulphur.	Manganese.
4·14	0·07	0·08	0·008	2·95

French Pig Iron.—The following analyses of pig iron from the Mont St. Martin blast furnaces are given by Mr. F. L. Garrison:[§]—

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[*] *Iron Age*, vol. xlv. p. 533.

[†] *Jernkontorets Annaler*, vol. xliv. pp. 389–466.

[‡] *Berg- und Hüttenmännisches Jahrbuch der k. k. Bergakademien*, vol. xxxviii. p. 407.

[§] *The Metallurgical Arts at the Paris Exhibition*, p. 99.

	Mn.	Carbon.		Si.	S.	P.
		Combined.	Graphitic.			
Foundry No. 1 . .	1·30	3·20	0·40	2·70	0·02	0·09
„ „ 2 . .	1·10	3·05	0·50	2·00	0·04	0·07
„ „ 3 . .	0·90	3·00	0·60	1·80	0·06	0·06
„ „ 4 . .	0·85	2·50	1·30	1·40	0·09	0·06
White basic pig iron .	1·50	3·00		0·20	0·04	2·00
Mottled basic pig iron	2·00	3·20		0·35	0·02	2·20

Aluminium in Iron.—Mr. H. M. Howe[*] gives the following analysis of a spiegeleisen which was transformed into grey iron by the addition of 3 per cent. of aluminium :—

Combined Carbon.	Graphite.	Si.	Mn.	P.	S.	Al.
4·8	0	...	13·65	...	...	...
0·93	3·45	1·30	11·75	0·05	0·01	3·19

The addition of aluminium drives the carbon into the graphitic form. This and other facts seem to indicate that the tabular fracture of spiegeleisen is not due to the manganese, but to the carbon, especially as ferrochrome shows a similar tabular fracture. A pig iron with the characteristic spiegeleisen fracture contained :—

Combined Carbon.	Si.	Mn.	P.	S.
4·0	0·02–0·05	0·20	2·7	0·03

Aluminium, added to some molten steel, quieted the metal completely, and caused it to pipe deeply. Little white specks were found on the surface, and proved to be alumina.

Flux used at the Bjelorezk Ironworks.—In connection with the analyses of pig iron given in the preceding abstracts, it is perhaps not out of place to give the following analysis of the limestone used as flux at the Bjelorezk Ironworks, Ural:[†]—

SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	P_2O_5.	SO_3.
0·10	0·35	0·50	54·10	0·84	trace	trace

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[*] *The Engineering and Mining Journal*, vol. l. p. 213.

[†] *Stahl und Eisen*, vol. x. p. 854.

III.—*BLAST FURNACE SLAGS.*

The Heat of Formation of Blast Furnace Slags.—Professor R. Åkerman [*] discusses the results of P. Gredt's [†] experiments relating to this subject, and compares his results with others obtained by calorimetric methods, the results being lower by this latter method. With regard to the specific heat of blast furnace slags, the author's experiments showed it to vary from 0·29 to 0·33, being less when the slag has a low melting point than when it melts at higher temperatures.

The author thinks that the differences of temperature which exist between the melting points of the various members of the Seger scale are greater than are usually assumed, and, further, that the excess of heat required for the formation of slags over that required to melt slags already formed is not so great when the slag is of a high melting point. Other possible causes for the variation in the results given by the two methods are also pointed out by the author.

Mr. H. M. Howe,[‡] by means of curves, compares the melting points obtained by P. Gredt with results previously obtained by Åkerman. The author also discusses the note by the latter, showing that his own results imply much lower melting points and much greater differences between the melting points of different slags. It is shown that there may be several explanations of these differences depending on the uncertainty of the bending points of Seger's pyramids, on the differences of the softening and melting points of previously fused or unfused silicates, on their latent heat, and on variations of the specific heat. The inference drawn is, that Gredt's results tend to confirm the most important ones of Åkerman.

Slag Cement.—It has been pointed out that only basic slags are suitable for such manufacture, and of these the dibasic lime silicates are the best. Professor Tetmajer,[§] however, considers that slag to be the most suitable in which the lime, silica, and alumina are present in the relative proportions of 46, 30, and 16.

The writer of the article observes that it was shown many years ago that only the granulated slag possesses hydraulic properties. Under the microscope a well-granulated slag shows bright grains, and only a few black opal-like substances. If these black grains are present in large numbers, the slag is useless for cement purposes.

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[*] *Jernkonterets Annaler*, 1889, Parts v. and vi.

[†] *Journal of the Iron and Steel Institute*, 1889, No. XI. p. 412.

[‡] *The Engineering and Mining Journal*, vol. xlix. pp. 637 and 675–676.

[§] *Stahl und Eisen*, vol. x. p. 523.

Granulated cement often contains from 15 to 30 per cent. of moisture. It has, therefore, to be dried, usually on iron plates. It is then ground in pug mills or other grinding apparatus, and mixed with lime and other additions. Usually the weight of the lime added is from one-half of that of the slag to an equal quantity. The mixture of slag and lime is finely ground, the fineness being such that, with the exception of from 8 to 10 per cent., the mixture will pass through a sieve having 180 meshes to the linear inch. The securing of a sufficient degree of fineness is the main point of the process, the earlier experiments relating to the use of slag for cement having failed owing to the coarseness of the grinding.

The slag cement manufacture at Donjeux, Haute-Marne, France, is given by the author as an example of a good variety. Its composition is as follows:—

SiO_2.	Al_2O_3.	FeO.	CaO.	MgO.	SO_3	Loss on Ignition.	Sand.
23·85	13·95	1.10	57·40	1·95	0·45	7·05	0·25

Results of mechanical tests of this cement are also given.

The slag cement manufactured at Bilbao has the following composition:—

SiO_2.	Al_2O_3.	FeO.	MnO.	CaO.	MgO.	$CaSO_4$.	CaS.
30·56	13·31	0·25	1·74	45·01	2·96	1·41	4·63

This cement is characterised by its large percentage of calcium sulphide, which colours the cement green when used under water. Its strength, however, is not impaired.

The cost of manufacture of the slag cement is also discussed, details being given.

The Use of Fluorspar.—Dr. Foehr,* in discussing the uses of fluorspar in the metallurgy of various metals, observes that, as regards the manufacture of pig iron, it is now no longer employed, owing to its comparatively high cost. In the rapid removal of scaffolds, however, it is most useful. In such cases it is usually blown in the form of powder through the tuyeres. A more important use, and one that was long kept secret, consists in its being employed in the manufacture of silicon-eisen or ferro-silicon. A metal made on a large scale in Upper Silesia, containing some 10 per cent. of silicon, and now greatly in use for foundry purposes, may be made in any ordinary form of blast furnace, and from any siliceous iron ore. A very basic slag, however, is necessary, and an addition of fluorspar to the charge enormously increases the readiness of reduction of the silicon. In all probability silicon fluoride is formed, and this is then reduced either by the hydrogen of the furnace gases, or even, it may be, by the coke itself. For this reason, too, an addition of fluorspar causes a blast furnace making white iron to make grey iron. It at the same time effects a considerable saving in the quantity of fuel required.

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* *Stahl und Eisen*, vol. x. p. 905.

Just as an addition of fluorspar greatly facilitates the manufacture of silicon-eisen, so, too, it is a most useful addition to a charge from which spiegeleisen is to be reduced. It is well known that manganese fluoride may be readily reduced by sodium to metallic manganese, but it is only recently that this reaction has been employed on a comparatively large scale in blast furnace practice, coke and iron taking, as reducing agents, the place of the sodium. A very basic slag rich in fluorspar is almost absolutely necessary if it is desired to manufacture ferro-manganese in a blast furnace.

Fluorspar is also employed both as a dephosphorising and as a desulphurising agent for steel. Even in the acid Bessemer process an addition of fluorspar is sometimes made, but it is evident that in such a case it must be employed with care, as it would rapidly corrode the lining. In puddling and in the open-hearth process its use has also been suggested.

For foundry purposes, especially in the remelting of very pure varieties of Swedish charcoal iron, the use of fluorspar is highly advantageous.

IV.—*FOUNDRY PRACTICE.*

The Herbertz Cupola.—Two hundred of these cupolas are now in use, whereof 167 are used for smelting grey pig iron, and 10 for melting steel; 22 are erected in the United Kingdom.

The manufacturers claim a number of advantages for this cupola over other types, both as regards cheapness of working, character of the metal obtained, and absence of escaping sparks. It will be remembered that in this cupola the draught is produced by the suction action of a steam jet.*

Sand-Moulding Machine.—An illustration is given in *Industries* of a sand-moulding machine. The pattern is formed or fitted on the upper and lower side of a plate which swings and slides on one of the pillars. The mould is formed in sand contained in two flasks, one above, the other below the pattern plate. The base of the machine carries two hydraulic rams, one inside the other. The plate on the outer ram head serves to lift the boxes and to compress the sand, while the inner ram ejects the mould from the flask. In operation the pattern plate is swung clear, the lower box is filled, and the plate is swung back. The upper box is then lowered on to it and filled with sand. The boxes and plate are then lifted up to the top of the machine, where the sand is compressed against the top plate. The boxes are then dropped and separated, the pattern is swung out, and the boxes are again brought together, so that the inner ram may expel the mould.

Rotary Pneumatic Moulding Machine.—A moulding machine constructed by the Atlas Company, Indianapolis, is provided with two heads, which are swivelled on a centre rod, forming one of the pillars of the machine. The pattern is raised or lowered by means of levers, which can be locked so that it is impossible for them to be moved at the wrong time. When the boxes are in position, one is ready for being rammed up, while the other is ready for the removal of the box, both operations taking place simultaneously. The pressing head is constructed with the required number of bags, according to the size of the machine, the bags being held in the top box. When the box is brought into position under the presser, compressed air is admitted, and first actuates a piston below the bottom plate, thus raising it and the box until the latter is brought in contact with the bags. The reason for this construction is, that there must necessarily be a little space to allow of the free movement of the head, and it is necessary to fill this space before the bags are put under pressure. As soon as the box is sufficiently raised, a valve is automatically opened, and the air admitted to the bags, thus ramming the box in a few seconds. The pressure of air used is 50 lbs. per square inch, which is found enough for practical purposes. After ramming, the pressure is relieved, the head swung round, the pattern drawn downwards, and the box removed. The sand is supplied from a hopper placed above the outward head. The used sand, after being riddled and mixed, is brought back by a travelling band and elevator to the hopper. A special light frame or box swivels on a joint, and can be brought above the box during filling, to allow for a surplus of sand being filled in to ensure complete ramming. The extra quantity thus supplied can be easily removed when withdrawing the pattern.*

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* *Stahl und Eisen*, vol. x. p. 822.

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* *Iron Age*, vol. xlv. p. 629; one illustration.

PRODUCTION OF MALLEABLE IRON.

The Protection of Puddlers from Furnace Heat.—M. H. Koppmayer* describes the method adopted at the Menden and Schwerte Ironworks in Westphalia for protecting the workmen at the puddling and heating furnaces from the heat radiated from the interior and the casing plates. A rectangular iron screen hangs from an overhead rail, and can be made to cover the whole working side of the furnace, or can be pushed aside when not required. The lower end is bent over into a gutter, which has a slight fall in the direction of its length, and the upper edge is provided on the inside, that nearest the furnace, with a pipe, bored through with small holes about ¾ inch apart. This is in connection with the service-pipe supplying water for cooling the sides of the bed. When in use, the inside of the plate is kept constantly wet from the supply-pipe, the small jets trickling down to the gutter at the bottom, and running away to the cooling bosh at the side. A notch at the bottom is left for the passage of the rabble, and a short inclined plate is provided for the cinder to run over; but, with these exceptions, the whole surface is screened by the water-cooled plate. At the time of balling-up, the water is shut off and the screen is run to one side, when the furnace is accessible in the ordinary way. This arrangement has worked so satisfactorily that it has been fitted to the whole of the puddling furnaces in the works, as it is found that the puddlers, being protected in great part from the exhausting effect of the heat, can work full time even in the hottest summer weather.

Iron Smelting in the Shan States.—The native methods of mining and smelting ore in the Shan States are described in a recent administrative report. At the Legya mines there are three shafts on the side of a hill, and at a short distance there are a number of shallow workings, from which most of the ore is obtained. The ore used to be carried on bullocks to the smelter, and bought by him at eight annas (one-shilling) the load. Each furnace has two workers, and at the present time one gets the ore, while the other makes the charcoal from pine wood. The furnace is made of earth, and has two openings. In the lower charcoal is placed, and banked up so as to keep in the heat. The ore is broken to the fineness of gravel, mixed with charcoal, and dropped in through the upper opening in the furnace. A blast is obtained with bamboo smithy-bellows. The smelting begins at 2 A.M., and is finished by sunrise. The piece of metal obtained, on being taken from the furnace, is cleft almost in two, and carried on a bamboo to the market. The yield varies according to the quality of the ore; in one case 50 lbs. of ore gave 10 lbs. of metal in less than four hours. The smelter works for four days, and sells his metal on the fifth day in the neighbouring villages. The smiths, as a rule, employ three to six men. They reheat the metal, and beat it out into a flat rod, which is cut into lengths and worked up. The metal is also used for making ploughshares.*

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* *Stahl und Eisen*, vol. x. p. 613; *Minutes of Proceedings of the Institution of Civil Engineers*, vol. ci.

The Adams Process.—In this process a mixture of ore and some 10 to 15 per cent. of coal is charged into a vertical rectangular chamber of slight width, tapering towards the top to allow of the easy descent of the charge. Through a number of openings at the sides of the vertical reducing chamber, reducing gas is allowed to act upon the ore in process of reduction. This gas is first heated to a temperature of from 800 to 1200° F. by passing through regenerator chambers.

One of these furnaces has been erected directly above an open-hearth furnace at the works of Park, Brother, & Co. at Pittsburgh. It is also stated to have been well tested at the Premier Steelworks, Indianapolis. The furnace, as erected at this works, is of the following dimensions:—Vertical cross section, 3 feet 6 inches below, 12 inches at top; length, 16 feet; height, 15 feet, with a top chamber 5 feet high, the same length and width as above given and 12 inches across, for drying the ore before entering the reduction chamber. The latter will hold of 65 per cent. ore (and the necessary admixture of coal) sufficient to give 20 tons of metallic iron. The reduction process requires five hours, so that the producing capacity of the furnace is about 100 tons of malleable iron in 24 hours. To produce this, it requires 6 tons of producer coal,

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* *Iron*, vol. xxxvi. p. 411.

16½ tons of coal intermixed with the ore, and 84 dollars for the labour, repairs, &c., employed, making a total of 1·04 dollar per ton over and above the cost of the ore. Nothing higher than a red heat is employed.*

The Electro-Deposition of Iron.—W. G. M'Millan† gives the composition of a number of iron solutions which have been recommended for use in the electro-deposition of iron. The best of these, the author adds, is that of Klein, which is made by dissolving ferrous sulphate in water, precipitating with a slight excess of ammonium carbonate, and redissolving with as little sulphuric acid as possible, avoiding an excess. The solution should be as concentrated as possible; it should never be allowed to become acid on use,‡ and should be used when warm. To keep the bath neutral, the anode surface should be very large as compared with the cathode surface, and the vat itself should preferably be of iron.

The fracture of unannealed deposited iron resembles that of cast iron. It may be so hard as to scratch glass, and Cailletet has shown that a sample of the metal he examined contained 240 times its volume of hydrogen. So hard, indeed, is the iron deposited in this manner, that use has been made of it for facing engraved die-plates of softer metal.§

In its relation to magnetism, deposited iron is comparable to mild steel. It has, however, been shown by Beetz that when deposited under powerful magnetic influence, as between the poles of a strong electro-magnet, and from solutions containing ammonium chloride, it will itself act as a powerful magnet, retaining its magnetism for a considerable period of time. The deposited metal rusts rapidly, and must, therefore, be carefully dried after removal from the bath.

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* *Iron Age*, vol. xlvi. p. 448.

† *A Treatise on Electro-Metallurgy*, London, 1890.

‡ Such a ferrous sulphate solution is difficult to work with. The double sulphate of iron and magnesium gives better results.—E. J. B.

§ See paper by Prof. Roberts-Austen, *Journal of the Iron and Steel Institute*, 1887, No. I. p. 71.

FORGE AND MILL MACHINERY.

Rolling-Mill Engine.—A pair of coupled reversing engines fo driving a steel cogging-mill are illustrated in *Engineering.*[*] Th cylinders are each 48 inches in diameter, and the stroke is 54 inches With steam pressure of 100 lbs. per square inch, the indicated horse power is 4500. The wheels have double helical teeth 7½ inches pitc and 18 inches on the face, and are of Siemens cast steel. The tota weight is 230 tons.

Hydraulic Bloom Shear.—A hydraulic bloom shear, designed b Mr. H. Aiken, is illustrated in the *American Manufacturer.*[†] Th machine weighs about 60,000 lbs., and it will cut hot steel 8 b 12½ inches. Two bolts only are used to hold the main cylinde to the housing, and they are set at an angle of 30° with the shearin edges, so as to give a large clearance. The knife-holder is guided i the housing, and is not attached to the hydraulic plunger, which simpl rests against it. The upward stroke is produced by a small cylinde suspended at the bottom of the shear.

Heavy Shearing Machine.—Illustrations are given in *Enginee ing*[‡] of two heavy plate- and rail-shearing machines of similar type The first of these is designed for cutting up old steel rails and scra and old boiler plates up to $1\frac{3}{16}$ inch, whilst the second will also cu hot bars up to 6¼ inches square. The main frame is cast in tw parts, which together weigh about 12 tons. Driving-power is furnishe by a small engine bolted on the frame of the machine, and having cylinder with a stroke and diameter of 15¾ inches. Steam at 57 lb per square inch is used, and the engine is run at 120 revolutions pe

[*] Vol. l. p. 277.

[†] Vol. xlvii. No. 4.

[‡] Vol. l. pp. 68-72; six illustrations.

minute. All gear wheels have double helical teeth, and the driving shaft is hollow and made of cast steel. The machine weighs about 23 tons complete. The plate shears can be disconnected, and the bar shears run alone.

New Lever Shear.—The *Iron Age* * publishes a description, accompanied by an illustration, of a lever shear manufactured by the Lloyd Booth Company, Ohio. This shear was designed especially for cutting socket iron with ends bevelled to an angle of forty-five degrees, thus scarfing the ends for welding at the same time as the iron is cut to length. An adjustable gauge is also attached to admit of the iron being cut to exact lengths, and it is so constructed that, at the instant the piece is cut off, the gauge moves back and allows the piece sheared to free itself.

The York Universal Beam-Mill.—In this mill the side rolls are introduced, which exert a simultaneous compression and reduction across the section. A number of advantages are claimed for this mill, both as regards first cost, the cost of operation, and the possibility of readily making beams or shapes of any width or height.†

New Blooming-Mill.—A description is published of a new blooming-mill erected at Chester, Pennsylvania. It is in connection with a new steel plant comprising two 5-ton converters.

The blooming-mill, built by Mr. J. P. Witherow, consists of two-high 32-inch reversing-mills, the rolls being 66 inches between collars. The housings are closed-top and stand upon V bed-plates, the latter extending the full length of the train. The upper rolls are balanced with steelyards and balance weights, and are also carried from the point of the screw by proper appliances. The screws are of steel, 7 inches in diameter, and fitted into wrought iron screw-boxes. The feet and windows of the housings are truly fitted and planed. The rider and carriages are fitted with Babbit metal bearings, and the first feed-rolls on both roller's and catcher's side are carried in housings in suitable bushings. The tables are 20 feet long from the centre of the mill on the roller's side, and 28 feet long on the catcher's side, with cast iron bed-plate the full length. The rollers are 5 feet long, 10 inches in diameter. The first eight rollers on each side are made of wrought iron pipe. The gearing is of steel. The rollers are spaced 14 inches apart, and are driven through suitable bevel gearings by a line-shaft 3½ inches in diameter, which is driven by a pair of small vertical reversing engines with 8 by 12 inch cylinders.

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* Vol. xlv. p. 761.

† *Iron Age*, vol. xlv. p. 805; three illustrations.

There are two hydraulic engine cranes provided for drawing ingots from the furnace and placing them on the blooming-mill table. Each crane has a 13-inch plunger and 8-feet stroke, with a swing of jib of 24 feet. There is one 4-hole heating furnace, the capacity of each hole being four ingots. One small billet-crane is provided for the purpose of loading sheared billets on trucks.*

The Mannesmann Process.—Professor Reuleaux † describes at length the Mannesmann process for rolling pipes, accompanying his description with drawings of the appliances employed in its manufacture. Tubes rolled in this way may be widened out again by reheating them, and introducing them into the rolls after changing the position of the latter to correspond. A still further enlargement is effected by a series of disc rolls, revolving at equal speeds in different directions.

The power required to produce these pipes is stated by Mr. Gordon to be very large, varying from 2000 to 10,000 horse-power, according to the dimensions of the pipe made. Thirty to forty-five seconds suffice for the manufacture of a tube 12 feet in length and 4 inches in diameter. Owing to the power stored in the fly-wheel between the intervals of rolling, a 1200 horse-power engine is adequate for the work to be done.

Great difficulty was experienced in the arrangement of the plant, owing to the defects of ordinary tooth gearing. How this was overcome is described in the paper. Difficulty, too, was experienced in coupling the rolls with the driving-shafts, owing to the necessity for very uniform driving, and special arrangements had again to be designed.

There are now four works in operation producing Mannesmann tubes, and a fifth is in course of erection.

Rolling Seamless Pipes from Hollow Ingots.—The Kellogg machine for converting hollow ingots into seamless pipes consists of a series of rolls, alternately horizontal and vertical, supported in housings which are secured to the bed-plate of the machine, and this, in turn, is anchored in masonry. A perfectly positive motion is secured throughout by properly proportioned gear-wheels.

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* *Iron Age*, vol. xlv. p. 593, with sheet of engravings.

† *Zeitschrift des Vereines deutscher Ingenieure*, 1890, p. 621; *Glückauf*, 1890, p. 361; *Dingler's Polytechnisches Journal*, vol. cclxvi. p. 22.

In working the mill, hollow ingots are first bloomed to reduce the thickness of the wall by one-half, and being then reheated, the bloom is slipped over the end of a mandrel held in the centre of the pass by an adjustable roller support, and is then pushed forward into the bite of the first pair of rolls, where it is rolled into an elliptical form. It then passes to the next pair of rolls, which reduces it, and rolls it to a circular form. The operation is then repeated, the result being that a finished pipe is turned out at one heat.*

The Norton Fluid-Rolling Process.—The fluid-rolling process of the Norton Company, Chicago, is stated to give satisfactory results in the case of steel, fluid steel being rolled into sheets of true gauge, free from blow-holes or other defects, and also free from scale.†

Trolley for Rolling-Mills.—A trolley designed by Mr. R. R. Gubbins for use in rolling-mills is illustrated in *The Engineer.*‡ It is intended to take the billets, or flats, when they leave the forge-train, and to pass them direct to the reheating furnace without waiting for them to cool, so that they can be laid on the peel by hand. The trolley mainly consists of two T-iron bearers mounted on four wheels. At the trailing end of the trolley is a lifter actuated vertically by a treadle. A recess is cut in the bearers in line with the lifter, deep enough to contain the blade of the peel. The billets are drawn over the peel as it lies in this recess by means of a rake. The peel is then lifted by the treadle and run into the furnace. Besides the fuel and waste of iron saved, the saving in time is large, and this results in an increased output from the furnace. It is estimated that ten heats of 2½ inch billets could be heated, if charged hot, in the same time that it takes to heat seven heats of cold billets.

Suspended Feed-Table for Rolling-Mills.—Mr. J. Morgan § describes a feed-table for rolling-mills which is suspended from above instead of being supported from below, and is especially adapted for rolling heavy beams. The supporting carriage runs on overhead gantries placed transversely to the table. These gantries can be raised or lowered by counterbalanced bell crank levers and a hydraulic cylinder so as to co-operate with three-high rolls. A system of belt gearing transmits power to an overhead shaft, from which the power is transferred to the carriage by an endless chain passing round sprocket wheels thereon, so that it can be moved to any position. Other chain gearing drives the carriage from one set of rolls to another. The feed-table carries live rollers mounted in a stirrup-frame open on one side. The rollers are driven by bevel gearing from one of the shafts on the carriage. A series of serrated rods under the table serves to turn the work as desired.

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* *Iron Age*, vol. xlvi. p. 632; five illustrations.

† *Ibid.*, vol. xlv. p. 911. ‡ Vol. lxx. p. 299.

§ *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

PRODUCTION OF STEEL.

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I.—*THE OPEN-HEARTH PROCESS.*

The Physical and Chemical Equations of the Open-Hearth Process.—In a lengthy paper of sixty pages, Mr. H. H. Campbell* discusses some problems connected with the manufacture of steel by the open-hearth process. Theoretical methods are partly employed to determine the various losses of thermal power and to investigate the chemical reactions. It is understood that the definite figures for one furnace and system are not generally applicable. Loss of iron is determined by weighing the slag and finding the percentage of iron it contains, different methods for this estimation being condemned. A method is given for calculating the weight of the slag at any period of the operation. In some cases the results are not in accordance with the calculation, as in the case of gases passing through the stove, but, in all cases, the details are given. The following is a synopsis of the argument and arrangement:—

General Data:
  Sect. 1. Chemical methods and physical data on which calculations are based.
Thermal Calculations:
  Sect 2–7. The methods employed, with examples.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof.

The Producer:

Sect. 8. General observations on certain elements of producer-practice. Sect. 9–10. Calculations in producer-work. Sect. 11. On averaging gas analyses. Sect. 12–15. Use of steam in producer. Sect. 16–18. Loss of thermal power in producer. Sect. 19. The gas used as a basis for subsequent calculations. Sect. 20. The general equation of the producer. Sect. 21–25. Experiments on the use of steam.

The Combustion of Gas:

Sect. 26–28. The theoretical combustion of various gases. Sect. 29–30. The latent heat of products of combustion of various gases. Sect. 31. Analyses of products of combustion. Sect. 32–36. Excess of air in products, and loss of heat thereby. Sect. 37–42. Deficiency of air in products, and loss of heat thereby. Sect. 43–59. Analyses and calculations of products of combustion. Sect. 52–57. The influence of the chemical reactions of the bath upon the products of combustion.

The Use of Oil-Fuel:

Sect. 60. Analyses and calculations of products of combustion.

The Chemical Equations of the Acid Process:

Sect. 61–68. The acid process, with particular regard to the formation and reduction of iron oxide.

The Chemical Equations of the Basic Process:

Sect. 69–81. The basic process. The thermal equation. Sect. 82–86. Determination of factors. Sect. 87. General thermal equation. Sect. 88. Consumption of coal in an empty furnace.

The Dynamical Equation:

Sect. 89. General observations.

The methods of analysis for ore, slag, and phosphorus are given; then follow the various physical constants which are required for the calculation of the specific heat and calorific value of mixed gas. For practical work, it is shown that variations in the specific heat are less than the errors in determination. The specific heat is taken at 0·317 per cubic metre of producer gas. At an average temperature of 750° C. the gas carries away 238 calories per cubic metre as it leaves the producer. The carbon ratio of the gas is the weight of carbon divided by the weight of hydrogen. This value depends primarily on the coal, but it is varied by the loss of carbon in the ash and tar, and by the steam introduced. In gases made under the same general practice, it indicates the special conditions under which a particular specimen is manufactured. Methods are given for calculating these values.

Two methods are now used for determining the efficiency of a producer, namely, the determination of the carbonic anhydride in the gas, and the calculation of its calorific power. As a theoretical standard both are deficient, as not only the heating power per unit volume of gas should be known, but also the coal required to produce that volume, and also the heat lost. The factors in question are the loss of carbon in the ash, and in the soot and tar, both of which reduce the carbon ratio. All the gases produced should be collected in order to calculate the efficiency. The weight of carbon per cubic metre of gas, and the volume of the gas per kilogramme of carbon, the calorific value per cubic metre and per kilogramme, are the data required to determine the weight of carbonic oxide and anhydride, and the amount of heat produced by the combustion. Examples are given of the calculations for the amount of carbon in the gas and the heat made in the producer. The averages of gas analysis depend on the loss of carbon in the ash, on the thickness and temperature of the fire, and on the amount of steam entering. Under a uniform system of working, the error caused by an incorrect system of averaging the gas is very slight.

A comparison is then made between two methods of making gas from coal containing:—Carbon, 82 per cent., hydrogen, 4·7 per cent.

Method A.—Open grates, no steam in blast. Loss of carbon in ash = 20 per cent. of weight of coal; hence carbon gasified = 62 per cent. of weight of coal. Loss of potential heat in ash per kilogramme of coal, 0·20 × 8080 = 1616 calories.

Method B.—Open grates, steam jet in blast. Loss of carbon in ash = 6 per cent. of weight of coal; hence carbon gasified = 76 per cent. of weight of coal. Loss of potential heat in ash per kilogramme of coal, 0·06 × 8080 = 485 calories.

Gas made by the two methods contains:—

	CO_2.	O.	C_2H_4.	CO.	H.	CH_4.	N.	Cal. Val.	C/H.
A . .	4·84	0·4	0·34	22·10	6·80	3·74	61·78	1209	12·58
B . .	5·30	0·54	0·36	22·74	8·37	2·56	60·13	1172	13·22

The gases obtained may be compared in the following manner:—

	A.	B.	C.
(*a*) Carbon in 1 cubic metre	0·1683	0·1680	0·1673
(*b*) Cubic meters of gas per kilo. of gasified carbon ($1 \div a$)	5·94	5·95	5·98
(*c*) Calorific value per cubic metre	1,209	1,172	1,170
(*d*) Calorific value per kilo. gasified carbon ($b \times c$)	7,181	6,973	6,997
(*e*) Calories lost in production of CO_2	1,248	1,374	1,349
(*f*) Calories lost in production of CO	1,760	1,791	1,803
(*g*) Total calories made in producer	3,008	3,165	3,152
(*h*) Total calories in gas ($d \times g$)	10,189	10,138	10,149
(*k*) Per cent. in producer ($g \div h$)	29·5	31·2	31·1
(*l*) Per cent. in gas ($d \div h$)	70·5	68·8	68·9
(*m*) Hydrogen per kilo. of gasified carbon	0·0795	0·0756	0·0752
(*n*) Hydrogen per kilo. of coal	0·0493	0·0575	0·0572
(*o*) Hydrogen in 1 kilo. of coal, by analysis	0·047	0·047	0·047
(*p*) Hydrogen from air and steam ($n - o$)	0·0023	0·0105	0·010
(*r*) Per cent. hydrogen from air and steam ($p \div n$)	4·5	18·3	18
(*s*) Cubic metres of gas per kilo. of coal $\left\{\begin{matrix}\text{62 per cent. of } b\\ \text{76 per cent. of } b\end{matrix}\right\}$	3·68	4·52	4·55
(*t*) Calories in producer per kilo. of coal $\left\{\begin{matrix}\text{62 per cent. of } g\\ \text{76 per cent. of } g\end{matrix}\right\}$	1,865	2,405	2,396
(*u*) Calories lost in ash per kilo. of coal	1,616	485	485
(*v*) Calories in gas per kilo. of coal $\left\{\begin{matrix}\text{62 per cent. of } d\\ \text{76 per cent. of } d\end{matrix}\right\}$	4,452	5,299	5,317
(*w*) Total calories per kilo. of coal ($t + u + v$)	7,933	8,189	8,198
(*x*) Per cent. in ash ($u \div w$)	20·4	5·9	5·9
(*y*) Per cent. in producer ($t \div w$)	23·5	29·4	29·2
(*z*) Per cent in gas ($v \div w$)	56·1	64·7	64·9

Of the above, the results in the column C are taken as a standard for all future calculations.

The loss of heat in the producer, resulting from the combustion of carbon, is made up of several factors, among which the following present themselves :—

(1) Loss in ashes, exclusive of the carbon they contain		...
(2) Latent heat of volatilisation		600
(3) Sensible heat of gas evolved		1085
(4) Losses due to vapour of water—		
(*a*) Evaporation of water in coal, and heating of resultant steam	18	
(*b*) Heating of the steam that passes through the fire undecomposed	38	
(*c*) Decomposition of steam	300	
		356
(5) Radiation and conduction		355
		2396

The heat of the ashes is nearly all utilised in heating the incoming air; their specific heat may be neglected.

Experiments were also performed to determine the amount of steam decomposed. Within the limits of error, it is found that the amount of moisture passing undecomposed through the fire is the same whether dry or saturated air is used in combustion.

The author then proceeds to consider the combustion of gas. The amount of oxygen required for several kinds of gas is calculated, and a comparison is made with relation to the latent heat of their product of combustion by considering such a volume of each as will give an equal calorific value. In ordinary producer-gas there is generally present 0·4 per cent. of oxygen. The additional oxygen required for complete combustion leads to the consideration of combustion with:—

(*a*) Excess of air:
    (1) The composition of the products of combustion with different amounts in excess.
    (2) The heat thus absorbed.
(*b*) Deficiency of air:
    (1) The composition of the products of combustion with different amounts of combustible matter escaping.
    (2) The potential heat lost for this reason.

Analyses of gases burnt under these conditions and of the products are given, and it is concluded that the average loss from imperfect combustion and from excess of air amounts to 4·5 per cent. of the total heat supplied when the escaping gases pass off at a temperature of 300° C. in excess of the incoming gases.

In the comparison of theoretical and practical results, certain disturbing factors are encountered in the chemical action of the flame upon the stock. The chemical history of the operation may be divided into three general periods:—(1.) The period of making the bottom and charging the furnace, during which the only causes tending to disturb theoretical calculations are the reactions occurring in the regenerative chambers. (2.) The period of melting, in which carbonic anhydride is formed by the action of the flame upon the carbon of the metal, and a large amount of oxygen is absorbed by the silicon and manganese. (3.) The period of adding ore, in which carbonic anhydride is formed by the action of the flame upon the carbon of the metal, and a small amount of oxygen is absorbed by the silicon and manganese.

To write the equation of these periods it is necessary to know the amounts of gas burned, of carbonic anhydride formed from the bath, and of oxygen absorbed during each period per unit of time.

Owing to the irregularities of working, it is impossible to accurately measure the consumption in every period of a charge. An average consumption of 700 lbs. of coal for each 2240 lbs. of product may be taken as sufficient for continuous working. The number of minutes in each period may be taken as 90, 450, and 120 minutes respectively, and the percentage consumption of fuel as 9, 75, and 16 per cent. The number of cubic metres of gas burned per minute will, similarly, be 34·6, 57·8, and 46·4 during the three periods, taking 1 kilogramme of coal as equivalent to 4·55 cubic metres of gas.

The next points to be determined are the effect on the gas of its passage through the chequer-work, and the chemical history of the bath. The reactions which may be looked upon as possible in heating a producer-gas to a high temperature are as follows:—(1.) A decomposition of hydrocarbons with deposition of carbon. (2.) A union of the carbon so deposited with the oxygen of steam, with formation of carbonic oxide or carbonic anhydride and free hydrogen. (3.) A union of the carbon so deposited with the carbonic anhydride, with formation of carbonic oxide. Whatever changes ensue from internal rearrangement, the condition and percentage of nitrogen in weight will remain unchanged, and this element may be used as a basis of comparison.

The results of several experiments show an increase of 3 per cent. in the carbon and 11 per cent. in the oxygen, whilst there is a decrease of 8 per cent. in the hydrogen. There would appear to be no leakage of air, but the C_2H_4 and part of the CH_4 have been broken up, thereby increasing the hydrogen; carbonic oxide is unchanged, and carbonic anhydride is increased in quantity. For practical purposes, the gas may be looked on as passing through the chequer-work unchanged.

The chemical history of the bath is essentially one of oxidation. Reduction by means of the flame alone does not obtain in practice. The rapidity of the oxidation varies with the character of the flame, the supply of combustible material, and the nature and disposition of the stock. The presence of a large proportion of hydrogen, either free or combined, in the gas, and a long exposure to a temperature just below the melting point, increase the amount of oxidation, whilst the absence of easily oxidisable elements in the metal concentrates this action upon the metallic iron. It follows that the data of one practice or one charge are worthless for general conclusions. Groups may be taken, however, under different conditions, whose histories in the furnace have been characteristic, and the results assumed to be representative.

A comparison is then made between the results drawn from two groups of experiments with producer-gas and with oil-gas. Full calculations are again given, and the composition of the waste-gases during the several periods is as follows :—

	Per Cent. by Volume.	
	CO_2.	N.
Empty furnace	18·2	81·8
During melting	17·9	82·1
During charging	18·7	81·3

From this it is evident that the chemical reactions in the bath do not materially affect the composition of the products of combustion.

The oil-gas used in these experiments was made by heating to 300 or 400° C. crude petroleum vaporised by superheated steam. The reactions between the steam and oil do not cause any gain, and much time in the chequer-work is required for the proper gasification. The behaviour in the chequer-work is then dealt with.

The author then discusses the chemical equation of the acid process with regard to the conditions obtaining with varying amounts of ore. In the slag the percentage of ferrous oxide increases owing to absorption from the ore, the silica remains constant owing to absorption from the bottom, and the manganese oxide is diluted. In the metal nearly all the silicon and manganese, about half of the carbon, and about 1 per cent. of iron are oxidised during the melting period, whilst, when the ore is being added, the silicon is reduced to about 0·02 per cent., manganese to 0·03 per cent., and carbon to the desired limit. As to the amount of reduction, some iron appears to be reduced from the slag, but the amount and percentage of ferrous oxide reduced rises with the amount of ore added, while the amount of oxide added to the slag does not increase proportionately with the increase of ore. Practical observation makes it certain that after the carbon is reduced below 0·15 per cent. oxidation of iron ensues.

Data are then given of three series of heats in the basic open-hearth process. A 5-ton furnace with dolomite bottom was used, lime was charged with the metal, and ore added as needed. Oil-gas was used as fuel. The first series was recarburised in the ladle, the others in the furnace. The materials used in the third series of seventeen heats are shown in the following table :—

Material.	Weight, Lbs.	Si.	Mn.	P.	SiO_2.	CaO.	MgO.	Fe_2O_3.
Bessemer pig iron	109,500	0·78	0·58	0·082	...	...	...	...
Basic pig iron	8,500	0·22	1·03	3·089	...	...	...	...
Scrap	102,000	0·05	1·11	0·094	...	...	...	...
Pit scrap	1,000	0·01	0·50	0·020	[5·00]	...	...	...
Ore	2,740	...	...	0·034	1·00	...	...	88·38
Lime	10,200	...	...	...	2·50	78·10	2·80	0·60
Dolomite	1,500	...	...	...	1·37	51·69	33·75	...
Wear of bottom	[4,200]	...	...	...	...	...	...	...
Ferro-manganese	1,275	...	79·76	...	...	...	...	...
Spiegeleisen	5,100	...	18·04	...	...	...	...	...

Wear of roof in 17 heats estimated to be 360 lbs. SiO_2.
Wear of ladle-linings, 1200 lbs., of which the SiO_2 will be about 750 lbs.
Sand on pig iron estimated to be 400 lbs.

The following table shows analyses of the metal and slag, (A) after complete fusion of the metal; (B) after beginning of the boil; (C) when the metal is ready for the recarburisation; and (D) the final product leaving the ladle :—

Third Series.	METAL.					SLAG.						
	Weight, Lbs.	C.	Si.	Mn.	P.	Weight. Lbs.	SiO_2.	MnO.	CaO.	MgO.	FeO.	P_2O_5.
Test A	...	0·71	0·06	0·33	0·046	...	19·21	11·12	42·16	6·64	13·68	5·149
,, B	...	0·34	0·01	0·25	0·022	...	16·37	10·36	42·78	7·87	16·29	4·848
,, C	192,750	0·12	0·01	0·22	0·013	...	15·08	9·01	42·16	8·45	20·34	3·850
,, D	197,720	0·16	0·01	0·49	0·018	30,780	15·75	14·11	39·05	10·40	16·65	2·961

From the table, the actual amounts of the elements in the slag can be calculated, and compared with the theoretical weights derived from the amounts charged (lbs.) :—

Third Series.	SiO_2.	MnO.	CaO.	MgO.	FeO.	P_2O_5.
Actual	4,848	4,343	12,020	3,201	5,125	911
Theoretical	3,383	3,946	11,201	1,069	...	1,092

The full calculations of the contents of the slags at the four periods, A, B, C, D, are then given, and the behaviour of the phosphorus and of the ferrous oxide is determined during these various periods.

The thermal equation of the furnace is then dealt with, by calculating the amount of heat required in the melting, and that generated in the furnace by oxidation and combustion. This is summarised, as follows, for each ton of product :—

	Calories.
Heat generated from coal	2,377,420
,, ,, from internal combustion	143,000
Total	2,520,420

	Calories.	Per Cent.
Heat lost as carbon in ash	140,650	5·6
,, ,, in producer	694,840	27·6
,, ,, in waste gases	246,710	9·8
,, ,, from imperfect combustion	69,390	2·8
,, ,, in melting and heating	290,000	11·5
,, ,, in radiation (by difference)	1,078,830	42·7
Totals	2,520,420	100·0

The losses of heat due to causes not connected with the bath amount to 94 per cent., and this ratio applies to a given time as well as a given production. During stoppages, the radiation decreases and the consumption varies according to the length of time and the temperature maintained. When economy of coal is carried too far, the first heat requires an abnormal amount of fuel. Records are given of the fuel consumption during a week's work, to show the extra amount of fuel required after the Sunday.

The method employed for the calculation of the weight of the slag depends on its manganese contents. Since the oxide of manganese comes from the oxidation of the metal, and the weight of the bath and its manganese contents are known at any two periods, the amount of manganese oxidised and absorbed by the slag is known. From this it follows that, if the actual weight of manganese oxide in the slag at one period is known, the weight at any other period can also be found. Thus, knowing the weight and the percentage of manganese oxide in the slag, the weight of the latter can also be determined.

The Open-Hearth Process.—Professor F. Kupelwieser * discusses the use in the open-hearth of fluid pig iron taken direct from the blast furnace. It is of advantage in those cases in which the weight of the pig iron used considerably exceeds that of the scrap added to the charge; more especially, that is, in the pig-and-ore process. In such cases, too, when the pig iron available is of a pure variety, its use in the fluid state is advantageous. Against these views various points have been raised. It has, for instance, been stated that the pig iron coming direct from the blast furnace is not so hot as that melted down in the open-hearth; but the author shows that this view cannot be sustained. Again, with regard to the opinion that it is difficult to raise rapidly to a higher temperature the pig iron charged into the open-hearth in a fluid state, the author observes that this difficulty might, in his opinion, readily be overcome.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 261.

For some months past three open-hearth furnaces at Witkowitz have been running continuously on pig iron taken direct from the blast furnace. A modification has, however, been adopted, which consists in passing an air-blast through the molten iron for a period of about two minutes. The result of this blow is to considerably reduce the percentages of silicon and manganese, as the following analyses show:—

Description.	Before the Blow.	After Two Minutes' Blow.
Silicon	0·95	0·26
Manganese	1·77	0·75
Carbon	3·39	3·03

The temperature of the metal when it reaches the open-hearth is but slightly increased by this process.

The charge consists of 90 per cent. pig iron, 10 per cent. scrap, and the necessary quantity of ore, together with some lime to reduce the percentage of the phosphorus. The process is very rapid, the three furnaces making about 17 charges in 24 hours. The fuel consumed is but from 10 to 12 per cent. of the weight of ingots made.

New Form of Open-Hearth.—K. Kreiss* observes that in the open-hearth furnaces designed by Batho, Koppmayer, and others, the regenerative chambers are placed at the side of the furnace. It is in the method of connection of these regenerators with the furnace that the author's improvement consists.

The furnace-bed, supported by I-beams, rests on three brick pillars. The regenerators are at each end of the hearth. If, therefore, the metal breaks through the bed of the furnace, it cannot destroy the regenerator chambers, and the arrangement possesses other evident advantages.

The laboratory portion of the furnace is in the form of a long rectangle, in order to utilise as much as possible the heat from the flame within the furnace itself, and at the same time to spare as much as possible the flues leading to the regenerators. At the charging side of the furnace are three doors—two large ones for charging, and a small one for the removal of slag and for sampling purposes. This small door lies between the other two. The regenerators are round brick receptacles, plated, and divided by a partition wall into two chambers —the one for gas and the other for air. Between the plating and the brickwork a space of 1·6 inch is left to allow for the expansion of the brickwork. This space is loosely filled with rubble or sand. The channels leading to the furnace are placed above one another at the sides of the dividing wall. The gas issues through two openings, the air through only one. Sketches illustrating the arrangement accompany the description.

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* *Stahl und Eisen*, vol. x. p. 771; four illustrations.

Chrome Iron Ore Lining.—The Tamaris Works * were the first to apply chrome iron ore as a neutral lining for the hearth of a Siemens-Martin furnace. Blocks of the ore are built-in with a mortar composed of two parts of the ore with one part of pure lime. Extra soft steel is made, but occasionally hard steel is produced. It is found that the metal does not remove chromium from the lining. The ore process can easily be employed, and silicon pig iron has no action on the hearth. At these works there are three furnaces of 6, 8, and 12 tons respectively. M. Vallon has advised the introduction of a deposit chamber for dust before the regenerators, and with this it is expected that very little repair will be required, as the chambers were practically the only parts that required repair.

Heating Furnaces.—Mr. D. K. Nicholson † draws a comparison between the Siemens, the Smith, and other heating furnaces. A Siemens furnace will probably require less repairs than any other reverberatory furnace. The gas and air come in by separate ports, and are fairly exhausted before they reach the outgoing ports, so that the brickwork is not damaged. In the Smith furnace the regenerators are built in the ends of the furnace, are open on the top, and are level with the bridge. This furnace is used for quick heating, the chequer-work is easily taken out and cleaned, and the various parts are not likely to become choked, as they are all near the surface of the ground. For good and careful heating the bottom must be well attended to, especially when mechanical charging devices are used. With good fire sand the bottom can easily be kept in good order. When only one tapping-hole is used it is much easier to keep a proper and even slope. A high place can be burned off by putting coal on it and letting the ashes flux it away, but the process of "burning down" is injurious to the furnace, as the temperature has to be very high. A low-carbon steel stands nearly as much heat as iron, but in heating high-carbon steel the temperature must be very carefully brought up to rolling point. Such steel should preferably be charged after being warmed by a wood fire built around it, if the furnace is hot. The furnace crown that gives most satisfaction is one that dips about 5° at each end for one-quarter of the distance, and then straight across, with the necessary arch sideways for support. A rough or uneven crown obstructs the draught and creates eddies. If steel is heated too much a crystalline structure is induced, but this can be partially remedied by lowering the temperature, and then bringing it up again to the required point.

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* *La Métallurgie*, through *The Engineering and Mining Journal*, vol. l. p. 213.

† Paper read before the American Society of Mechanical Engineers; *Engineering*, vol. l. pp. 118–119.

Various plans have been attempted to burn the smoke from a green fire, but they have been abandoned. Explosions are prevented by building a fire on the hearth when starting the furnace.

Vertical or pit furnaces are only used to reheat ingots soon after casting. They save labour in charging and drawing, but are not equal to horizontal furnaces for heating ingots evenly. The greatest difficulty is to get rid of the cinder. Soaking pits require no fuel, and the ingot is manipulated with greater ease and speed than in pit furnaces. The ingot must, however, speedily be transferred to them to furnish the required heat, and at least 90 per cent. of the ingots from the Bessemer process could not be treated in soaking pits.

Furnace-Charging Devices.—Mr. S. T. Wellman* describes a new device for charging heating and melting furnaces. In consequence of the large size of ingots and other products, the machinery at present in use is cumbrous, and the bottom of the furnace is often much injured. The aim of the author's machine is to do all the work of taking the ingot from the truck, raising it, carrying it into the furnace, and placing it wherever desired, dropping or lowering it into place, and, when the ingot is ready for rolling, lifting it from the bottom, bringing it out of the furnace, carrying it along and depositing it on the table in front of the rolling-mill. All the valves controlling the movement of the machine, and the opening of the furnace-doors, are worked by one man, who rides on the machine. The boiler pump, and engine for operating the machine are all carried on a truck running on a track. The ingot is grasped by tongs mounted on a moving framework, the forward end of which rests on wheels which can be lifted by a hydraulic cylinder. This frame is moved in and out of the furnace by means of a hydraulic cylinder, and this operation causes the pivoted tongs to grasp the ingot at the same time. One heater, a helper, and a boy to run the machine can handle 100 to 200 ingots per turn. The practice of partly heating cold ingots in one furnace, and heating them fully in a second furnace, is readily carried out with this machine.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

This machine is also adapted, in a modified form, for charging materials into open-hearth furnaces. Boxes made of plates are placed on small trucks and filled with the required materials. These trucks are then run in front of the furnace, where the machine picks up the boxes, runs them into the furnace, dumps them, and removes the empty boxes. The frame carries a T-headed bar, the head of which fits into a socket on the charging-box. The frame is lifted and moved forward in a similar way to that in the former machine, and the bar is twisted so as to dump the box by a special twister.

Mr. H. M. Howe* also describes one of these machines of Mr. Wellman, and states that by its aid one man and a boy can charge 38,000 lbs. into a melting furnace in fifteen minutes. A similar machine is at work at Weissnichtwo, and charges 12 tons in thirteen minutes. Peel-heads instead of boxes are used, and the peel consists of a telescopic rod mounted on trunnions, so as to lift and advance the peel-head. The machine runs on rails on the charging platform.

Mr. A. Harrison's machine is adapted for charging furnaces mounted around its centre. It is adapted for charging ingots into heating furnaces. The machine swings around a fixed centre, and the peel-head is raised and lowered, and also moved radially by means of hydraulic cylinders.

Fuel-Charging.—A good charging arrangement must distribute the entire charge of coal uniformly and rapidly, and in pieces of any required size. It must be air-tight, and even during the charging no appreciable quantity of gas must escape. It must be possible to determine, with ease and without escape of gas, the rate at which the coal is sinking, whether a fresh charge is required, and to prevent its sticking. The apparatus should be easily handled by boys or old men. Lastly, it must be durable, cheap, and easily repaired.

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* *The Engineering and Mining Journal*, vol. l. pp. 214–215; illustrations.

These requirements are only approximately fulfilled by any appliance in use. Consequently, Landgren [*] has devised a new form, illustrations of which he publishes. The apparatus has the appearance of a double cup and cone. The upper cone is raised by means of pulleys about a foot, and a truck containing 2 cwt. of coal is tipped into the charger. The cone is then lowered, and the lower cone raised, the coal thus falling into the furnace. The entire apparatus costs £14.

Park Gate Steelworks.—A description of the Park Gate Steelworks, near Rotherham, is given by Mr. C. J. Stoddart.[†] The present works consist of 5 blast furnaces, 4 plate and sheet mills, 3 bar-mills. 80 puddling and ball mills, 180 coke-ovens, 5 steam-hammers, 25 shears, and other necessary appliances. The weekly out-turn can be brought up to 1400 tons of pig iron, 850 tons of sheets and plates, 450 tons of bars, and 500 tons of coke. Steam is generated by waste heat from the furnaces.

The steelworks commenced operations in 1888. There are two acid and two basic 25-ton open-hearth furnaces, supplied from twelve Wilson gas-producers. The ingots are lifted by steam travelling cranes, and are charged hot into the reheating furnaces. The cogging-mill is driven by a pair of 50-inch reversing engines at 60 revolutions per minute. The train consists of a pair of 36-inch slab rolls 7 feet long, and a pair of 36-inch cogging rolls 9 feet long. The top rolls are balanced by hydraulic power. Live rollers are used to transfer the slabs, and the ingots are turned on edge by mechanical appliances.

The plate-mill is probably the largest and most novel in this country. It is run at 36 revolutions per minute by a pair of horizontal engines with cylinders 50 inches by 5 feet stroke running at 80 revolutions. The train consists of one pair of breaking-down rolls 36 inches in diameter and 7 feet long, one pair of finishing rolls 36 inches in diameter and 12 feet long, and one pair of hard rolls 30 inches in diameter and 8 feet long. The 7-foot and 12-foot top rolls are balanced by hydraulic power, the adjusting screws of both mills being adjusted by small engines with 7-inch cylinders and 10-inch stroke. The large plate-shears have 10-foot blades with 30-inch gap, and can cut plates 1¾ inch thick and 7 feet wide. Plates can be rolled in this mill up to 11½ feet wide, and up to 60 feet in length. The hydraulic power for these works is supplied at a pressure of 700 lbs. per square inch, and is supplied by a pair of 20-inch horizontal engines. At the end of the plate-mill is placed a large roll-turning lathe with 33-inch centres and 26-foot bed. This is served by a 35-ton travelling crane, which traverses the whole length of the mill. The steelworks are capable of turning out 700 to 800 tons of steel per week, and from 400 to 500 tons of plates. The total area of the works at Park Gate is 70 acres, and at the Holmes, 30 acres. Seven locomotives, 500 waggons, and 31 horses are in use.

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[*] *Jernkontorets Annaler*, 1890, p. 38.

[†] *Proceedings of the Institution of Mechanical Engineers*, 1890, pp. 396–401; 4 plates,

Steelworks and Rolling-Mills.—Some notes on recent improvements in German steelworks and rolling-mills are given by Mr. R. M. Daelen.* An endeavour is being made to arrange converters and open-hearth plant for combined working, both in charging and casting. A general arrangement of plant for this purpose is shown. The four vessels are in line; adjoining them are the casting-pit and the ingot-cranes, and beyond these, in the same direction, the open-hearth furnaces. The ladle of direct-metal is brought by a track on the general floor-level to the hydraulic lift, by which it is raised to the charging-level of the converters. The track at this level may be laid either on the crane or on the chimney-side of the vessels. In the former position the supports of the track partially intercept the view of the vessel's mouth from the pulpit during the operation of pouring; in the latter position long runners for the pig metal are unavoidable.

Since, however, the advantage of emptying the charging-ladle by tapping, rather than by tipping, has come to be recognised, another arrangement would recommend itself, namely, the providing of each pair of converters with a hydraulic lift, placed between them. This arrangement exists in several works elsewhere than in Germany. It permits short runners, and does away with the upper charging-level. The design of the steel ladle car is usually determined by local conditions. Illustrations are given of a locomotive crane. A simpler form is also described, in which the vertical movement is dispensed with.

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (advance proof).

The trucks for conveying fuel, lime, and refractory materials might be replaced by a wire-rope tramway.

For a plant embodying the above-described general features, a building of moderate height will be suitable. The roof can be set so low that the greater part of the converter-flame will be carried off on the outside, reducing interior smoke and heat to a minimum. This makes it practicable with advantage to adopt the same form of roof for both the converter and the casting-house.

In the construction of the converter itself the use of a middle ring and journal, made in a single piece, has been generally abandoned. It is now constructed of heavy plate, to which cast steel journals are screwed. Tar dolomite bricks made in a hydraulic press make an excellent basic lining. Mechanical appliances are used in making the bottom. The ball pulveriser is used for grinding slag for manure. The cause of the great progress in basic practice lies chiefly in the reduced period of the blow. The excess of blast is reduced from 150 to 30 per cent.

In the instance illustrated the casting-house is common to both converter and open-hearth plant, and forms the connecting-link for both with the soaking-pits, blooming-mill, and finishing-mill. Unfired soaking-pits allow the reduction of large ingots to $\frac{1}{100}$ or $\frac{1}{150}$ of the original cross-section, and this may also be extended to the production of rails. The blooming trains are mostly two-high, and have feed-rollers which are advantageously driven by belting. Most of the bloom shears are worked by hydraulic pressure (up to 500 atmospheres), which is furnished by a steam-jack near the shears. This consists of a vertical steam-cylinder with single-acting piston, on which the steam presses from below, the upward prolongation of the piston-rod constituting a water-plunger in a smaller cylinder. The high water-pressure works upon the pressure-plunger of the shears, and, after the cut is ended, the water returns into the smaller cylinder. This construction is made practicable by means of an arrangement for regulating the speed of the steam-piston by that of the water. In this way a considerably higher number of strokes per minute has been attained than is the case with shears driven by rotary motion. This number ranges up to 25 strokes per minute. The beginning of the cut is determined by the operator, so that the danger of waste by cutting too short is avoided.

For further reduction of the blooms to rails, ties, and shapes three-high rolls are generally used. In the most approved form the upper and lower rolls are adjustable and the middle one is fixed. In the manufacture of plates the three-high roll, with loose middle roll, is largely used, especially in preliminary rolling for the sheet-mills.

Darby's Recarburising Process.—Mr. H. M. Howe* gives the following particulars of Darby's recarburising process as carried on at the Brymbo Steelworks. Gas carbon is preferred for the filter, as it is dense, free from sulphur, and readily absorbed by the molten steel. The metal is run through a perforated brick-lined chamber, into which carbon is dropped from an overhead funnel, little by little, as it is dissolved. About 85 per cent. of the carbon added is accounted for by the increased carbon contents of the steel. The remaining 15 per cent. is blown away or burnt. The usual practice is to run about two-thirds of the steel through the filter, and the remaining third is run directly from the furnace into the ladle. The carbon contents of the steel can be regulated generally within a variation of 0·03 per cent., as shown by the author in several tests. An analysis of one steel gave:—

C.	Si.	P.	Mn.	S.
0·31	0·02	0·041	0·15	0·014

This metal rolls well, and has an elongation exceeding 20 per cent. in 8 inches, and tensile strength between 26 and 30 tons per square inch. The author then proceeds to discuss the views advanced by Mr. A. D. Elbers † on this subject, that this process is only suitable for removing oxygen from overblown metal, and that it does not really carburise the metal.

Electricity in Steelworks.—At the Solingen Steelworks a central station has been erected, and equipped with Lahmeyer's dynamos and electro-motors. In this way the entire works are lighted, and power transmitted to forty steel presses, lathes, and drilling-machines. The convenience, safety, and cheapness of this method have been so clearly proved that it is intended to use electric power exclusively throughout these works.‡

Electric Lighting Plant at the Terni Steelworks.—The electric light installation at the Terni Works, the largest ironworks in Italy, was completed in 1887 at a cost of £5000. The extent of the undertaking will be evident from the following figures:—

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* *The Engineering and Mining Journal*, vol. l. pp. 4–6.

† *Ibid.*, vol. xlix. p. 553; vol. l. p. 95.

‡ *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 401.

Description.	Square Metres.	Square Feet.
Total area of works	190,660	2,047,104
Area of buildings with glow-lamps	3,540	38,105
Area of buildings with arc-lamps	29,593	318,542
Total area of buildings	44,615	472,246
Area per arc-lamp:—		
(*a.*) in open-air (56 lamps)	2,572	27,686
(*b.*) in buildings (43 lamps)	688	7,405
Area per glow-lamp	30	322
Area per glow-lamp in offices	18	193

Altogether there are about 300 glow-lamps of 25 candle-power each. The electric current for the arc-lamps is generated by 12 dynamos, each of 10 horse-power, and each worked by a 20 horse-power turbine. For the glow-lamps there are two 25 horse-power dynamos, worked by a common turbine of 50 horse-power. Detailed descriptions of the installation have been published in the German technical journals.*

The Homestead Steelworks.—Eight 15-ton basic open-hearth furnaces have recently been erected at the works of Messrs. Carnegie, Phipps, & Co., Pennsylvania. The furnaces are placed in two rows, each of four furnaces. From each row a line of rails runs to the circular casting pit, situated at one end of the building. The casting ladle is lifted off its carriage before pouring.†

Basic Steel at Chattanooga.—The first 25-ton basic open-hearth furnace has recently been put in operation at the Chattanooga Works of the Southern Iron Company. The hearth is made of dolomite found in the neighbourhood. The second furnace, nearly completed, will have a dolomite bottom and magnesite sides. It is the intention of the company to use the ordinary coke iron made in the Chattanooga district, the only stipulation being that the pig iron shall be under 1 per cent. of silicon and 0·06 sulphur. The iron used in the first heat made was that produced by the Company, No. 5, containing, silicon 0·81, sulphur 0·02, and phosphorus 0·69 per cent. The scrap was mixed iron and steel. The analysis of the steel produced was as follows:‡—

Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.
0·11	0·012	0·021	0·069	0·57

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* *Uhland's technische Rundschau*, vol. iii. p. 283; *Dingler's Polytechnisches Journal*, vol. cclxxviii. pp. 125–128.

† *Iron Age*, vol. xlvi. p. 856.

‡ *Ibid.*, p. 497.

The Manufacture of Ingot Metal.—L. Pszezolka * observes that, in basic ingot metal, when the bath has been decarburised to the desired degree it is not homogeneous, but some portions are much richer in carbon than are the rest, and after recarburisation the resulting metal is similarly irregular in its chemical composition. This is, however, not so marked in the case of acid metal, owing to the equalising action of the acid slag. With a view of imitating this action of the slag in the basic process, the author adds towards the completion of the decarburising stage siliceous materials to the bath of slag. This, he finds, has the desired effect.

II.—*THE BESSEMER PROCESS.*

The Basic Bessemer Process.—In reviewing the present condition of the steel industry, Kintzlé † points out the great importance of basic Bessemer metal in view of the rapidly increasing production. Whereas in England, Germany, Austria, Luxemburg, and France the production in 1883 did not exceed 564,000 tons, in the year 1889 it amounted to 2,272,000 tons, Austria and Germany heading the list. In the district of the German Customs Union there are 14 works, with some 50 converters, working with the basic process. During the period under consideration many new uses for basic steel have been found. The methods of conducting mechanical tests have been greatly improved, and in the laboratory accurate rapid methods have been devised, so that the time occupied by determinations has been considerably shortened. Thus, the determination of phosphorus may now be effected in 30 minutes, carbon in 30 minutes, manganese in 100 minutes, silicon in 60 minutes, and sulphur in 4 hours.

The improvements in the working of the basic process consist in the altered construction and increased size of the converters and better arrangement of the plant. By taking the pig iron direct from the blast furnace, when the latter works with sufficient regularity, the cost of remelting is dispensed with. A notable improvement is the shortening of the duration of the blow for a charge of 10 to 11 tons to from 12 to 15 minutes. Great improvements have also been made in the preparation of the basic lining, the best results being obtained

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* *Stahl und Eisen*, vol. x. p. 611.

† *Zeitschrift des Vereines deutscher Ingenieure*, 1890, p. 713.

with pulverised dolomite mixed with boiled tar, and containing 1
25 per cent. of magnesia.

The selection of basic flux is of importance. Pure burnt lim
found to answer the best, the quantity added varying from 15 to
per cent. Assuming that the value of the phosphoric acid in the
produced is 1d. per lb., and that to a ton of metal 660 to 770 lb
slag is produced, the amount received for 17 per cent. of phosph
acid in the slag would represent 10s. per ton of metal produced.
the annual production of basic slag of about 815,000 tons, of w
quantity Germany produces 540,000 tons, probably not a single
is left unused.

The Chester Steelworks, Pennsylvania.—This new Besse
plant consists of two 5-ton converters, provided with all accesso
The converters are 7 feet 3 inches in diameter inside the shell, and
constructed in three sections—a nose, a bottom belt, and a lower
The nose is made of ½-inch plate iron sheets, being butted together
held with lap straps on the inside. The middle and lower sections
of ⅝-inch plate iron. The total height from the bottom parting to
top of the nose is 12 feet 3 inches. To the middle section of
converter are attached two cast iron trunnions, the journals b
15 by 16 inches, and one being formed for the passage of air
the blast-pipe. The converter is supported upon a girder by a
iron pedestal. Upon one trunnion is mounted a spur-wheel 35¾ in
in diameter, 4-inch pitch, and 10-inch face, into which engages the
steel rack. Each converter is provided with one hydraulic cyli
for rotating, 16 inches in diameter, and of sufficient stroke for wor
the converter by means of a suitable rack. The bottoms, of which
were provided with each furnace, are of wrought iron with cast
wind-box, and are 7 feet 3 inches in diameter and arranged fo
tuyeres. Under each converter is a hydraulic ram 10 inche
diameter, 32 inches stroke, which is firmly riveted to the base-
carrying the converter columns. Round each converter is a plat
below the trunnion centre, supported by channel bars resting
columns carried from the general level. This platform affords a
means of access to all parts of the vessel.

There are three cupolas with drop bottoms having shells 108 in
in diameter, and intended to line to about 76 inches at the cruc
The total height of the shell from the mantle-plate is 34 feet.
cupola is provided with six tuyeres, one charging-door frame,

cinder-notch, one tapping-hole, one drain-hole, and a large opening in the shell at the base fitted with plate-bars and wedges. The lift for the cupola is a standard hydraulic freight hoist with cylinders 8 inches in diameter and the necessary stroke, and having a lifting capacity of 2500 lbs., exclusive of the weight of the platform. The iron ladles have a capacity, when lined, of 14,000 lbs. of melted metal when filled to within 4 inches of the top. There are five steel ladles, having a similar capacity, when filled to within 2 inches of the top. Each ladle is fitted with cast steel trunnions, having the fixed castings of the teaming harness attached. The trucks for carrying the bottoms are adapted to a 30-inch gauge, the wheels being 20 inches in diameter.

A small heating furnace, having a heating surface of 15 by 24 inches, is furnished for heating ferro-manganese to a dull heat.*

The Phœnix Steelworks.—In connection with Professor Wedding's paper on the progress of the German iron industry since 1876, *Stahl und Eisen* † publishes drawings of the Bessemer shop of the Phœnix Steelworks, in the Laar district.

Converter Slag.—G. vom Rath ‡ observed in a converter slag from Witkowitz, Austria, crystals resembling an augite, probably babingtonite.

They were identical with others observed in 1873 by H. Scheerer and P. Groth in a Bessemer slag from Hörde.

Basic Iron.—A variety of metal made by the South Tredegar Iron Company of Chattanooga, Tennessee, is termed "basic" iron. It is made from highly phosphoric iron, rich in silicon, by a short blow in a Bessemer converter, followed by treatment in gas-heated puddling furnaces. §

Basic Bessemer Steel.—Mr. J. B. Nau || publishes articles on the subject of "Basic Bessemer Steel; its Manufacture and Cost." The percentages of the silicon and phosphorus which may be present in the pig iron suitable for this process are stated as follows by the author:—Silicon, 0·6–1·0; phosphorus, 1·7–2·0; manganese should be 1·5 or 2 per cent.

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* *Iron Age*, vol. xlv. p. 592.

† Vol. x. No. 11.

‡ *Stahl und Eisen*, vol. x. p. 655.

§ *The Bulletin*, through *Iron Age*, vol. xlv. p. 939.

|| *Iron Age*, vol. xlvi. pp. 365–440.

The author refers to the absorption of sulphur by the pig iron when melted in the cupola. About two-thirds of the sulphur in the coke passes into the iron, the percentage being greater when the metal is rich in silicon.

After the completion of the blow, as much slag as possible should be removed before the recarburisation, but even then rephosphorisation takes place, as the following results show:—

	Phosphorus, per Cent.					
Before addition of spiegeleisen	0·047	0·033	0·061	0·024	0·059	0·042
After ,, ,,	0·062	0·057	0·085	0·041	0·094	0·064

The pig iron employed in the production of these samples contained about 1·8 per cent. of phosphorus. The author instances a case in which, when very soft metal was being made, the casts obtained from the metal in the upper portion of the ladle, touching the slag, were so hard that the metal could be worked into cold chisels.

Statements of cost are given, showing results in favour of the basic as compared with the acid Bessemer process.

The Cost of Bessemer Steel.—Mr. C. D. Wright, in his report, to which reference has already been made in the consideration of the cost of production of pig iron in the United States, has also published statements relating to the cost of production of Bessemer steel. One steelworks, believed to be in eastern Pennsylvania,* worked during 244 days in 1889 on rail steel with two converters, and produced during that period 116,080 tons. The materials used per ton of steel produced included 2200 lbs. of pig iron, 422 lbs. of scrap, and 73 lbs. of ferro-manganese and spiegeleisen. The following is a statement as to the cost of the ton of ingots, excluding insurance, interest, depreciation, and freight of product:—

	Dollars.	
Pig iron	15·795	
Scrap	2·949	
Manganiferous material	1·278	
Total material	20·022	
Value of scrap	0·510	
Net cost of material		19·512
Labour		1·522
Officials and clerks		0·108
Fuel		0·919
Supplies and repairs		0·453
Taxes		0·010
Total cost, ingots		22·524

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* *Iron Age*, vol. xlvi. p. 179.

The cost of production in the United States of mild steel ingots suitable for the manufacture of nails is given as follows:—

Cost of Soft Nail Steel Ingots.

Items of Cost.	No. 1. First Half 1889.	No. 2. 1888.	No. 3. 1889.	No. 4. 1889.
Days running	127	263	261	269
Total product, tons	28,343	61,895	68,790	74,130
Daily product, tons	223	235	264	276
Proportion of materials, lbs. per ton—				
Pig iron	2,385	2,230	2,393	2,261
Scrap	51	37	...	24
Ferro-manganese	20	22	25	20
Cost of material, dollars—				
Pig iron	16·282	17·316	17·000	17·539
Scrap	16·423	17·445	...	16·188
Ferro-manganese	51·875	51·462	56·400	56·299
Cost per ton, dollars—				
Pig iron	17·335	17·241	18·161	17·701
Scrap	0·375	0·287	...	0·173
Ferro-manganese	0·469	0·513	0·627	0·496
Total material	18·179	18·041	18·788	18·370
Less value scrap	0·088	0·132	0·018	0·080
Net material	18·091	17·909	18·770	18·290
Labour	1·923	1·800	1·716	1·573
Officials and clerks	0·116	0·080	0·051	0·075
Fuel	0·383	0·609	0·535	0·474
Supplies and repairs	1·050	0·672	0·616	0·524
Taxes	0·012	0·004	0·006	0·003
Totals	21·575	21·074	21·694	20·939

As examples of the relative cost of manufacture of steel rails in the United States, on the Continent of Europe, and in the United Kingdom, the following comparison is made:—

Cost of Steel Rails.

Items of Cost.	United States.	Continent.	United Kingdom.
Days run	258	148	137
Product, tons	118,460	48,193	32,926
Product per day, tons	440	326	240
Quantity and cost of material used—			
Ingots or blooms, tons	120,762	50,540	39,687
Pounds per ton	2,384	2,349	2,700
Cost per ton, dollars	24·392	23·816	15·644
Cost per ton of rails, dollars—			
Material	25·963	24·976	18·856
Less value scrap	0·849	1·554	2·461
Net cost material	25·114	23·422	16·395
Labour	1·382	2·010	1·368
Officials and clerks	*	0·231	0·025
Fuel	0·417	0·679	0·449
Supplies and repairs	0·774	0·683	0·352
Taxes	*		
Totals	27·687	27·025	18·589

It is believed that these statements relate to works provided each with two converters, but the *Iron Age* points out that those relating to the works situated on the Continent and in the United Kingdom are evidently very far from typical.

* Not reported.

FURTHER TREATMENT OF IRON AND STEEL.

The Manufacture of Sheet Iron.—A manufacturer who, during more than twenty years, has been connected in Austria with the manufacture of sheet iron, discusses * the progress which has been made in recent years with the manufacture of very thin sheet iron, up to 0·04 inch in thickness, and of sheets of middling thickness, from 0·04 to 0·16 inch. These sheets necessitate the use of different methods of manufacture, in itself a sign of the progress of recent years. In this industry, hammers have given place to rolls, and iron to steel. Formerly the metal used for these sheets came from hearths and puddling furnaces; and though these processes have to a very great extent been replaced by the Bessemer and open-hearth methods, this replacement has not been quite complete. It is now generally recognised that even the very finest varieties of puddled iron are unsuited to the manufacture of the best sheets, owing to the slag which is always present. This slag, acting on the carbon in the metal, gives rise, on welding, to the formation of flaws and blisters. The thinner the final product, the thinner, too, will be the skin covering the flaw; and this, on tearing, gives rise to irregularities in the appearance of the metal, and may even render it useless. Not only, however, are puddled iron sheets covered, as a rule, with a multitude of small blisters, but the metal itself is unsuited to rolling by the "doubling" method. It has so great a tendency to weld, that the doubled sheet, after rolling, is most difficult to tear asunder. As a rule, too, it contains so much sulphur that the metal has a tendency to red-shortness, and this leads to the cracking of the edges, which is occasionally very noticeable—sometimes, indeed, to such an extent that after the cracked sheet has been rolled sideways, the cracks have been so enlarged that the amount that requires to be trimmed off may reach as much as 30 per cent., as compared with, say, 20 per cent. in di metal. Careful choice of the metal and fuel used, employing a addition of spiegeleisen or ferro-manganese, might, of course, g improve the quality of the puddled iron, but such selection may too costly. Gas puddling furnaces working with plenty of yield a cheaper product, but the metal is of poorer quality, a author, in the connection, refers to a previous article by Goedicke concluding his consideration of this question, the author observe the recent progress in the puddling process, of which the gas fur the outcome, is of little value, as, although gas furnaces produce a and fairly good product, it is not that fine-grained iron which best adapted for fine sheets.

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* *Stahl und Eisen*, vol. x. pp. 773-783, 856-862, and 947-955, with illustrations.

Of much greater importance in Austria than the puddling pro the hearth, which, in the forest-clad regions of Austria-Hunga Sweden, still plays an important part in the manufacture of sh the quality to which the author refers, and which process, f thinner varieties of sheets, it is almost impossible to replace. It seem that it is impossible at present to produce these very thin from ingot iron. Such sheets must be doubled three or four time in such cases ingot iron appears to show that same cohering cha which is so marked in the case of puddled iron. The hearth, ever, is only of importance in those places where charcoal is and only that variety of hearth should be employed even then consumes but little charcoal. The author describes such an im hearth by the aid of sketches. A hot blast heated by the wast is employed, and the excess of heat from two hearths is emplo preheating the iron to be used in the process and for reheati sheets. For every ton of finished sheets about 0·9 ton of char required in this furnace, or, allowing for the utilisation of the heat, only half that quantity. The loss of metal varies from 16 per cent., according to its quality. The principle underlyin Lancashire hearth-process is considered by the author, who ob that in front of the tuyere the temperature reaches 1600° C upwards. It is observed that the effect of this high temperature cause liquation phenomena to take place in connection with the produced in the hearth, the result being that metal rich in imp separates from the remainder of the mass. This remains in the of a dense, homogeneous bloom of metal, coarsely granular in stru

The methods of arrangement and manipulation of hearths are des

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[*] *Journal of the Iron and Steel Institute*, 1889, No. II. p. 424.

at some length, sketches accompanying the description, as also does an account and sketch of a small sheet-mill.

Except for the finer varieties of plates, all these slower processes have now given way to others making ingot metal, the basic processes having on the Continent of Europe made rapid headway in this direction.

Even the softest samples of acid Bessemer metal were not found suitable for the purpose, and similar objection was made to acid open-hearth metal. The introduction of the basic process not only enabled a softer and more suitable metal to be made, but its cost of production in Austria was less, cheaper materials being used. For cartridge-cases, however, the basic metal possessed, as a rule, too little "spring." One of the greatest objections to the basic process consists in the large number of blow-holes in the ingots, an irregularity which it has not hitherto proved possible to avoid, and this in turn leads to irregularities in the prepared sheets which may greatly depreciate their value. The use of silicon, of course, diminishes to some extent this liability to blow-holes. Too much of it, however, deteriorates the quality of the metal, and the author believes that it is in improved methods of casting that the cure for such blow-holes is to be sought. The author refers to a device for this purpose suggested by F. Kapfl. This consists in imparting a series of slight vertical jerks to the mould and its contained metal during the progress of solidification.

The extent to which a blow-hole, once formed, is eliminated during the after-treatment of the metal depends, other things being equal, on the pressure employed and the amount of work done on it.

Small ingots are radically bad, and the welding should be very carefully performed. Unfortunately, an ingot, even when it contains but 0·2 per cent. of carbon, will not stand, on first heating, a temperature at all approaching a welding heat. It does so much better on the second heating. It is, therefore, better in the first place to reduce large ingots to slabs of a thickness of about 6 inches, then to cut these in pieces, and, using a gentle welding heat in a gas furnace, which they will now stand well, to roll them down to bars.

The most important improvement in the manufacture of sheets was due to the use of rolls instead of the hammer. At present the only instance of the use of the hammer is to be found in the manufacture of Russian sheet, and even in this case rolls are now being employed.

The author describes the kinds of rolls in use, and their arrangement. He is not in favour of the Lauth three-high roll system. The doubling system gives better results. The method of rolling the sheets is then considered, and attention is drawn to the kinds of furnaces in use for annealing purposes.

The annealing of the sheets is effected either in a closed box or by direct heating. The further treatment of the annealed plates is described by the author at some length, both as regards the actual treatment and the furnaces and apparatus employed; special attention being drawn to the system of acid dipping employed by Messrs. Hughes, Chemery, & Co., a drawing being given of the apparatus.

Machine for Expanding Sheet Metal.—A novel machine is illustrated in *Engineering* * for producing trellis-work or metallic mesh from strips of thin sheet steel. The material made is similar to that produced by cutting a series of slots in a sheet of paper and pulling out the ends. This machine cuts the slots, and at the same time bends the cut strip to the form desired. In general, the machine may be compared to a sheet-metal shears. Strong upper and lower jaws have cutters attached; the upper jaws are moved vertically by an excentric, and the lower jaws, which are bevelled, are moved longitudinally in guides when the upper jaw descends. A cam is used to bring back the lower jaw. The cutters are variously shaped, so that, as they cut the metal and force the cut part down, different forms of mesh can be produced. The material used is mild sheet steel of from 12 to 20 gauge thickness, and in strips about 7 inches wide and 8 feet long. Cutting commences at one corner, and a lattice is produced from 2 to 4 feet wide, and only slightly shorter than the original strip, at the rate of about 7 feet per minute. Diamond shapes, from 1¼ to 4 inches between the parallels, are largely produced and used, but almost any pattern may be made. Mr. Golding † also describes this material and the machine used for making it. The name wire-netting is given to it by the author in default of a better.

Plate Flattening and Straightening Machine.—Illustrations are given in *Engineering* ‡ of a plate flattening and straightening machine, designed to straighten plates of any length up to 6½ feet wide, and from ¼ to ¾ inch in thickness. The machine weighs about 19 tons, and is self-contained on one foundation plate. The rolls are 12¼ inches in diameter, five of steel and two of cast iron.

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* Vol. I. pp. 100–102; illustrations.

† Paper read before the British Association at Leeds, 1890.

‡ Vol. I. p. 278.

Breaking of Masses of Iron by Blasting.—In a paper, illustrated by diagrams of the various bodies experimented on, H. Münch * describes the methods of breaking large masses of iron or steel by blasting. He classes the masses under the following three heads:—

1. Bodies which can be blown to pieces by charges of dynamite laid loosely on or against them. This class comprises railway bridges in time of war.

2. Hollow bodies, where the charge can be placed as in a bore-hole, or whose capacity is sufficiently large to admit of their being filled with water, into which the dynamite charge can be placed. This class comprises large guns, press cylinders, and boilers.

3. Huge masses of steel or iron which must be bored into as if they were composed of rock, and then blasted. This class comprises rolled steel and iron plates, cofferdam piles, and blast furnaces. In this case it is found that bore-holes from 0·83 to 1·18 inch in diameter and repeated small charges should be employed. The author has found that a ton of iron can be blasted into pieces sufficiently small for recasting at a cost of less than 5s.

Planing-Machine.—Illustrations are given in *Industries* † of a large horizontal and vertical planing-machine capable of planing up to 16 feet in length and 8 feet in height. A massive cellular base-plate, extending the whole area of the machine, forms a substantial foundation for the standards, and in its front part it is provided with T grooves, which are planed out of the solid metal. Three strong uprights support two horizontal slide beds, which are framed together. The lower of the latter has an extra wide bearing surface to sustain the vertical bed. The vertical bed is made of box section, and has fitted on it a vertical slide, which is balanced by a weight passing within the bed. The vertical slide carries relieving tool boxes for horizontal and vertical planing fitted on to the grooved transverse slide. A self-acting feed traverse is given to the latter. When a horizontal traverse is required, it is obtained by moving the vertical bed by twin screws, and the vertical traverse of the slide on the bed is obtained by one screw suitably disposed. Quick return motions are fitted in each case. The peculiarity of this arrangement is, that the cutting-feed is obtained by the same screws. The single screw gives the feed when horizontal planing is going on, and the twin screws th required when the machine is planing vertically. Adjustable st are fitted to regulate the length of the stroke, and the machine c be automatically reversed and the feed-motions applied. The char from the quick-planing to the slow-feed traverse is made by means clutches. These machines are made in various sizes, the largest which has a capacity of 21 feet by 18 feet, and weighs nearly tons.

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* *Wochenschrift des österreichischen Ingenieur- und Architekten-Vereines*, 1890, p. 59.

† Vol. ix. pp. 57–60.

Punching - Machine.—A double-ended punching - machine w Z- and L-iron cutters is illustrated in *Engineering*.* This mach will cut Z-iron from 4 to 10 inches, and angle-iron of any size. T punching ends are fitted with twin punches for punching two holes once, and one or both ends can be thrown out of gear.

Steel-Sawing Machine.—Illustrations are given of a new fo of horizontal saw for sawing runners or gates off steel castings. T saw revolves in a horizontal plane, and is carried by a saddle wh is capable of being raised on a slide on the framework to a height 3½ feet; besides which, the saw can be fed forward horizontally throu a distance of 16 inches. The machine carries a 28-inch saw, and w cut solids 8 inches thick. Quick return and disengaging gear are p vided. Raising and lowering are done by hand, by means of wo gearing driving a drum, round which a wire rope passes and is c nected over pulleys to the saddle. Bevel gearing on the saddle is dri from a vertical shaft by a feather and key-way.†

Machines for Drilling Square and Polygonal Holes.—T machines have recently been brought out for the purpose of drilli square or polygonal holes. The first of these, the Ainley-Oakes machi will drill round or square holes. It is similar in appearance to an ordina drilling-machine, and the same method of driving and feeding is us The spindle, however, consists of three parts: first, an outer slee carrying a bevel wheel, and driving an intermediate sleeve by a k way and feather; secondly, an intermediate spindle having a set five cams on each end, which are arranged to be used when drilli holes of various sizes; thirdly, an inner spindle which carries the to and is fed downwardly by hand or automatically. The bearings for spindle consist of four flat plates of hard steel, and are made in halves. These parts are adjusted by right and left hand screws, and one pair has round holes which engage the circular part of the spindle when round holes are being drilled. The other pair of plates are shaped so that as the cams work in them the cutting edge of the tool describes a square path. This pair is adjusted by means of a lever so as to engage with any required cam, in order to drill a hole of the desired size.

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* Vol. l. pp. 124 and 126.

† *The Engineer*, vol. lxx. p. 148, illustration; *Industries*, vol. ix. p. 180, illustrati

The second machine is a modification of the above. It will bore holes of any shape—square, hexagonal, triangular, or oval—and is also provided with a slotting-machine motion. The spindle moves about the centre of a ball joint, the top end only being provided with a roller or wheel, which travels round the inner edge of an annular template, being pressed outwards by a pair of spiral springs. The inner spindle carrying the tool serves a different purpose to that in the above-named machine. In this case, by lowering the spindle, the size of the hole to be drilled can be varied with accuracy, whilst to drill a parallel hole the whole head of the machine is lowered in suitable guides in the main framing. The templates in this machine can be readily changed, and any desired shape of hole can be drilled. The tool is made so that its cutting edge terminates on the centre line of the spindle, and is suitable for any sized or shaped hole. The machine is provided with a slotting motion, so that shapes of the most complicated form can be finished.*

Electric Drill.—An electric drill is in use at the Brooklyn Navy-yard for drilling holes in ships' plates from ½ to 1½ inch thick, or more, in positions where the use of a power-drill is almost impossible. The box containing the drill is 18 inches in length over all; it contains the motor and a flexible shaft, 6 or 8 feet long, for working the drill. The motor runs at 2800 revolutions per minute, and is geared down. An inch hole can be bored through half-inch iron in less than 30 seconds.†

Electric Motors in Workshops.—Mr. C. F. Jenkin ‡ describes the various applications of electric motors to drills, tube-cutters, and cranes. Cast steel is used in the construction of the field-magnets, as it can be formed readily into any desired shape, and it holds a position intermediate between cast and wrought iron in its magnetic perties. The various factors which determine the construction of s motors are then discussed, and particulars are given of several app tions. With a common drilling-machine a ¾-inch hole was bore the rate of about ¼ inch per minute through Bessemer steel, with expenditure of one-fifth horse-power. An electric drill, running a revolutions per minute when loaded, was driven by worm-gearing f a shunt-wound motor. The weight of the motor was about 56½ and it drilled a ¾-inch hole through a ¾-inch plate in 45 seconds, electric power required being 0·732 horse-power. The author describes a small motor and saw for cutting tubes out of boilers, a 10 horse-power motor which was used for driving a travelling-cran

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* *Industries*, vol. ix. pp. 52-53, illustrations; *Iron*, vol. xxxvi. p. 46.

† *The Engineering and Mining Journal*, vol. l. p. 52.

‡ *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cii. p. 307.

Angle-Iron Bevelling-Machine.—Illustrations are given * of latest form of a machine for bevelling angle- or Z-iron, especially use in shipbuilding work. The machine is mounted on rails in f of the furnace, and draws out the bars and bevels them at the same t The bevelling-rollers reach right down to the heel of the angle, turn the sides in or out as required; they also smooth down the e of the rivet holes. The bar is still hot enough when it leaves machine to set to any curve without reheating.

Hoffmann's Kiln Adapted for Annealing Wire.—The Hoffm Kiln has been adapted for annealing wire by M. Bourry.† In one f there are six vertical cylindrical chambers, in each of which an ann ing pot is placed. Each chamber communicates with the next means of horizontal and vertical flues. Gas is led to one of chambers by means of a movable pipe connected to a central gas- which is surrounded by the outlet for the products of combust Hand-holes are made in the covers of the chambers for the purpos admitting air to cool the pots down, and to heat this air for com tion in the chambers in which the pots are being heated. It is st that a 6-pot furnace will anneal 4 tons of wire per day, with a sumption of 10 lbs. of coal for 100 lbs. of iron wire, or 15 lbs. of for 100 lbs. of steel wire. The wire is in the furnace about tw hours, and one man per shift takes care of the whole apparatus. pots have false bottoms to admit of the ready removal of the wire.

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* *The Engineer*, vol. xlix. p. 457; *Iron*, vol. xxxvi. pp. 69 and 73, illustration *Génie Civil*, vol. xvii. pp. 97–98, illustrations.

† *The Engineering and Mining Journal*, vol. l. p. 101; illustration.

The Sweeney Wire-Nail Machine.—This machine, it is claimed, possesses considerable advantages over other nail machines, both as regards simplicity of construction, ease of operation, cheapness, and rapidity of work. A machine making from 1 to 2 inch nails can produce over 500 such nails a minute.*

The Bryant Wire-Nail Machine.—Illustrations of this machine are published in the *Iron Age.*† The wire, after being straightened by straightening rolls, is fed forward by feed mechanism, gripped between dies, and is firmly held by them while the head is being formed by a header. As soon as the latter operation is performed, the upper die is raised and the wire is fed forwards until the desired length has been supplied; the upper die again holds the wire while the cutting dies are operated, cutting and pointing the nail. Then the finger or clearer strikes the nail and throws it into the shoot leading to the receiver.

Machine for Shaping Axles.—Illustrations are given in the *American Manufacturer* ‡ of a machine for shaping axles by hydraulic pressure. The blank is shaped in dies by lateral pressure, given by hydraulic rams, and the end collars are put on and the axle compressed longitudinally by plungers which work in the ends of the dies. Pivoted dogs are thrown into action to catch the blank after the dies separate, so that they can readily be removed from the machine.

Steel and Malleable Iron for Railway Vehicles.—A report read before the Convention of Master Car-Builders deals with the application of steel and malleable iron to railway vehicles. Fox's pressed steel under-frames are mentioned, and also other steel parts, such as draw-bars and other parts stamped from steel. The use of malleable castings appears also to be extending rapidly. Its use is principally confined to those parts formerly made of grey iron, though it is sometimes substituted for wrought iron. In the use of this material it is preferable to expose as much skin as possible, as that part of the casting is the strongest. The committee recommend the adoption of standard forms for pressed steel and malleable castings wherever possible.

The following facts are noted:—Malleable castings are lighter than cast iron, and also cost about the same when the weight is taken into account. The price of iron and steel beams and plates is sufficiently low, and the use of pressed steel frames will result in the gradual substitution of iron and steel for wood in the construction of railway vehicles.*

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* *Iron Age*, vol. xlvi. pp. 401–404; ten illustrations.

† Vol. xlv. p. 861.

‡ Vol. xlvii. No. 1.

The Munton Process for Manufacturing Tires.—A plant on this system is in operation at the works of the Chicago Tire and Spring Company, at Melrose, near Chicago.

The ordinary method of manufacturing tires is to cast a solid ingot of cylindrical shape, which is then heated and upset under a steam-hammer until its height is reduced and its diameter enlarged. After a hole has been punched in its centre the ingot is then placed on a beak or pike horn and hammered by blows struck on the periphery. It is then again heated and placed in a rolling-mill and rolled into a tire of the required diameter.

Mr. J. Munton,† the designer of the plant, considered that this method was wrong in principle, as hammering a steel ingot down to about one-third its original height must tend to produce strains and cracks near the periphery. He therefore adopted the following method:—

1. The ingot is cast with a hole cored out large enough to admit a small roll.

2. The ingot is heated and taken to the rolling-mill, where its top is sheared off and the bloom left of a given weight. At the same heat and by the same operation the bloom is also roughed out by the roughing rolls of the mill and edged down by horizontal rolls.

3. The bloom is reheated and placed in the tire-rolling mill, where it is rolled and finished to the exact inside and outside diameter required.

A detailed description of the mill is also given.

Heavy Rails in France.—According to the *Schweizerische Bauzeitung*,‡ the line of one of the more important French railways is now being relaid with steel rails of a much heavier type than those hitherto employed. The head of the rail has been increased in thickness by 0·47 inch. This, it is considered, may safely be worn away without endangering the rail, and even as much as 0·79 inch may, it is thought, be thus removed without danger. The new rail has a weight of 88·7 lbs. per yard. It is 5·58 inches high, the width of the head being 2·44 inches; the centre-rib is 0·71 inch thick. The rail length has been increased from 26 feet 3 inches to 39 feet 4 inches.

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* Read at Point Comfort, Virginia, June 1890; *Iron and Steel Trades Journal*, vol. xlvii. p. 109.

† *Iron Age*, vol. xlvi. pp. 521–523; six illustrations.

‡ *Stahl und Eisen*, vol. x. p. 468.

Steel Rails.—M. Mussy [*] discusses the various qualities of steel employed in the manufacture of rails, and reviews the opinions expressed by Mr. P. H. Dudley and M. Gruner. The author agrees with M. Gazes in considering that chemical analysis is not a sufficient test of the hardness, as it does not take into account the conditions under which the metal was produced nor the work to which it has been subjected. The influence of the temperature of fusion on the quality of the metal is considerable, as shown by M. Couard. Open-hearth steel rails, which are produced at a lower temperature than Bessemer steel rails, are inferior to the latter. M. Gazes considers that rails of considerable hardness are preferable to those made of softer metal. Generally speaking, however, the purer the metal the better are the results, both with regard to accidents and breakages and with regard to resistance to wear. The degree of hardness cannot be definitely stated; it depends on the conditions under which the rail is used. In countries with a variable climate the rail should be softer than where the weather is more constant. The required hardness of the metal can only be determined by submitting the rail to tests which reproduce the conditions under which it is to be used. Of this nature are tests under compression and tension, and tests under a falling weight.

It has been determined to strengthen the permanent way on the Russian railways, so that heavier engines may be used and an increase in speed obtained. For this purpose standard dimensions for the sleepers have been officially promulgated, and the rails also are to be of steel 5·31 inches in height, and are to weigh 73·12 lbs. per yard. The rails previously in use have varied from 54 to 58½ lbs. per yard.[†]

A small apparatus designed by Mr. W. Schilling for tracing rail profiles is illustrated in *Engineering.*[‡] It has been in regular use on several railways in Germany and Russia. A full-size section is drawn, and shows the wear or deformation of the rail. A small carriage moves on

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[*] *Annales des Ponts et Chaussées*, April 1890; *Mémoires de la Société des Ingénieurs Civils*, 1890, pp. 184–185.

[†] *Annalen für Gewerbe und Bauwesen*, 1890, p. 140.

[‡] Vol. l. p. 336.

horizontal guides, and carries a pencil and two pointers. These
zontal guides are supported on a second carriage which moves on
tical guides, so that any motion in a vertical plane can be given t
pointers and pencil. The apparatus is clamped to the rail, and th
pointers are so arranged that one travels over the side of the rail
then the other is turned into position to trace the top.

Railway Fish-Plates.—Mr. R. W. Hunt* is of the opinion that
will be used instead of iron for the manufacture of railway fish-p
He gives the following specifications for iron and steel fish-plates.

Iron fish-plates:—(1.) The iron must be of good quality and p
nicked on one side, and broken suddenly on an anvil at the freezing
perature; must show at least 70 per cent. of fibre. If four plate
of six, taken at random, fail, the load should be rejected. (2.) The
must be rolled true to the templates, without fins, and must be pun
accurately to dimensions given. (3.) The punching must be do
that the plates are not distorted or bulged. Shearing punches sh
used. (4.) Any plates not complying with these conditions ma
rejected.

Steel fish-plates:—(1.) The metal is to be either Bessemer or
hearth steel. (2.) By preference, it shall not contain over 0·10 per
of phosphorus, and not over 0·17 per cent. of carbon. Should
phosphorus exceed 0·10 per cent. the carbon shall not be over 0·1
cent., but the phosphorus shall never exceed 0·12 per cent. (3.)
steel must be heated with care, and never up to the limit of sa
(6.) Analyses are to be furnished. Sections 4, 5, and 7 are the sa
sections 2, 3, and 4 in the case of iron fish-plates.

Steel Sleepers.—Mr. T. Ker† describes some new forms of
railway sleeper. Inspection of injured rails show that flaws ar
veloped in the head of the rail directly over metal sleepers, bu
flaws occur between the sleepers when wooden ones are used.
this and various reports, the author was led to devise an elastic
sleeper. These are made from a shallow trough section; the end is
down and up again, then it is carried back under and parallel t
part whereon the rail beds, and is riveted to the main body o

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* *Transactions of the American Institute of Mining Engineers*, vol. xix. (a
proof).

† *The Indian Engineer*, vol ix. pp. 81–82.

sleeper. Before it is riveted it may again be bent down and up again to form a second anchoring support. Chair jaws are punched out, and the rail is secured by a key, or other forms of chairs may be used.

Cast Iron Coated Water-Pipe.—Mr. T. W. Yardley* gives specifications for cast iron coated water-pipe, of which the following is an abstract:—(1.) The pipe shall be that known as the hub and spigot, 12 feet in length, and shall conform to the drawings. (2.) The metal shall be of the best quality, made from ore without admixture of cinder; it shall be tough, and be easy to cut and drill by hand. (3.) Each pipe to have cast on it a distinctive mark and its serial number. (4.) The pipe shall be cast in dry sand vertical moulds of the required diameter, and shall be free from imperfections, truly cylindrical, of full diameter, and with interior and exterior surfaces concentric. (5.) Chemical analyses are to be supplied, and also a daily report. (6.) Each ladle of iron shall be numbered, and a daily record of the work kept. (7.) The shell is to be of uniform thickness, and any greater variation than 10 per cent. shall cause the rejection of the pipe. (8.) From each ladle a test bar 26 inches by 2 inches by 1 inch shall be cast. On supports 24 inches apart this bar must support a centre-breaking load of 2000 lbs. per square inch, with a deflection of not less than $\frac{3}{16}$ inch before breaking. (9.) Failure to meet these requirements shall cause the rejection of the iron. (10.) Wrought iron templates are to be provided by the maker. (11.) The pipe shall be cleaned, inside and outside, without the use of acid. If the pipe is stripped above a dark-blue heat, all sand must be removed from the outside immediately. (12.) When cleaned, the pipe is to be heated to 300° F., and dipped in coal-pitch varnish at an equal temperature. On removal the coating shall fume freely, and set hard within an hour. (13.) When coated, the pipe shall be tested hydrostatically with pressures not less than 450 lbs. per square inch for 6 to 8 inch pipes, 400 lbs. for 10 to 12 inch, 350 lbs. for 16 and 20 inch, 300 lbs. for 24 and 30 inch, and 250 lbs. for 36 inch diameter and upwards. During testing, the pipe should be struck smartly with a 3-lb. hammer at various points. (14.) Any pipe falling 5 per cent. short of standard weight is to be rejected, and not more than 2 per cent. excess is to be paid for. (15.) All special castings, such as bends,

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* *Transactions of the American Institute of Mining Engineers*, vol. xix.

&c., are to comply with the above requirements. (16.) Applian the inspector are to be supplied by the maker free of cost.

File Steel.—Mr. W. Molin * publishes the following anal steel suitable for files:—

	C.	Si.	Mn.	S.	F
Swedish Bessemer . .	1·25	0·05	0·12	trace	0·
American crucible . .	1·30	0·21	0·25	0·03	0·
American "cast iron" .	0·70	0·97	0·04	0·06	0·

The Manufacture of Spiral Tubing.—Works have recentl established at Detroit for the manufacture of spiral tubing, an trations of the machinery employed have been published in t *Age.*† At present four winding-machines are in place, one of will make pipe 14½ inches in diameter. The maximum length is 24 feet. The arrangement consists in the rotation and si neous axial progress of a large mandrel, upon which steel ribbo wound. These vary in width for different sizes of pipe, but are about 4 inches. The gauges range between 20 and 26 B. steel, and 24 for copper and brass. They are prepared b trimming them to the required width, after which they a through a bath of zinc chloride, and then through a tinning they are then bevelled. Before the steel ribbon is fed to the m it is put through a bath of soldering fluid, and from this throu solder-pot and on to the machine. The solder-pot is placed diately below the mandrel, the pot being heated by oil. The m is heated by forcing through it from end to end a current of air by the burner under the solder-pot. The mandrel is made pieces hinged together, with a wedge or key inserted between After the pipe is made the wedge is withdrawn about 12 inche causing the mandrel to collapse. The pipe is held stationar the mandrel is quickly withdrawn by reversing the motion u winding. The convolutions of one ribbon follow directly upon of the previous one. All kinds of sheet metal, singly and joi be employed. Thus tubes of steel, lined and covered with b copper, may be produced. The capacity of the plant is abou feet of tubing per shift of ten hours.

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* *Iron Age*, vol. xlv. p. 545.

† Vol. xlv. p. 1071; vol. xlvi. p. 85, four illustrations.

Malleable Iron Castings.—A committee that has reported to the United States Master Car-Builders' Convention[*] gives the following rules to be observed in the production of malleable iron castings:—

1. Never run abruptly from a heavy to a light section.

2. As the strength of malleable iron lies in the skin, expose as much surface as possible. A star-shaped section is the strongest possible form in which a casting can be made. For brackets use a number of thin ribs instead of one thick one.

3. Avoid all round sections; practice has demonstrated this to be the weakest form. Avoid sharp angles.

4. Shrinkage, generally, on castings will be $\frac{3}{64}$ inch to the foot smaller than the pattern.

The Hartz Tube Welding Machine.—The Hartz tube welding machine has been made for the purpose of cutting, preparing, piercing, and welding tubes, such as boiler tubes. The machine is provided with a series of cutting and forming rollers, which revolve round a central mandrel on which the tubes are cut, formed, and afterwards rolled when the joint is placed upon it at a welding heat. The rollers and mandrel are cylindrical or tapered, and are interchangeable, so as to cut the tube and to flare and otherwise prepare the ends.[†]

Electric Welding.—A rapidly alternating current flows mainly in the outer layers of a conductor, but still the bars used for welding get heated all through. This apparent difficulty is explained by Professor O. T. Lodge.[‡] In welding, the current has to cross the joint, and the current initially passes at the points of contact only. As soon as the bar is softened by the heat, the conductivity of the portion near the joint is much less than in other parts of the bar, and hence the heat continues to be localised where it began. Then again, the outside of the bar is subjected to excessive air-cooling, while the inside of the bar tends to retain its heat. Lastly, it is pointed out that the hotter the joint is, the less will be the heat generated in the other and cooler portions.

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[*] *Iron Age*, vol. xlvi. p. 44.

[†] *The Engineering and Mining Journal*, vol. xlix. p. 707.

[‡] *Industries*, vol. viii. pp. 616–617.

Several devices for electric welding, invented by Mr. C. L. Coffin, are illustrated in the *Engineering and Mining Journal.** The surfaces to be welded are heated by what may be called an electric blow-pipe; that is, an electric arc, which is diverted in a strong magnetic field. The first device is used for small articles, and consists of a small carriage on which are mounted the carbon pencils and an electro-magnet with its pole near the arc. In another form, the joint may be heated by the arc, or by the usual process of passing the current through the joint. An electrically operated hammer and its anvil can be moved over the joint to complete the operation. In the third form illustrated, the resistance of the joint is increased by a thin plate of mica, and the operation is performed within a magnetic field, which is stated to reduce the current required.

Mr. H. Lemp † describes the rise of electric welding, and states that it has been accomplished with continuous and alternating currents; secondary batteries and unipolar machines may be, and have been, used. Under certain circumstances it may be desirable to use the continuous current, but the alternating has been found best adapted, by reason of its more economical production at low electro-motive force and large volume. There is, however, another advantage, arising from the fact that self-induction assists materially in heating the exterior of the bar to be welded, thus compensating for the loss by radiation which is apparent in the continuous current process. Two methods of distribution are in use, the direct and indirect. In the former, an alternating dynamo is used, having two windings on the armature, one of which furnishes currents rendered continuous by a commutator to excite the field magnets, and is controlled by switch and rheostat; the other, consisting of a single turn of heavy copper cable, furnishes the welding current, which is led through collector and brushes to movable copper clamps arranged to receive and guide the welding objects during the operation. In other forms the field magnet is the movable part, in which case no heavy currents have to be carried through the collector and brushes. No direct welders are built at present for currents above 4000 amperes. The indirect method of distribution is now almost exclusively used. In its simplest form it consists of one alternating dynamo, self or separately excited, and one welder, which is a transformer, with the necessary clamping and operating appliances. The self-exciting dynamos used are from 1000 to 20,000 watts output, and may be regulated by means of a reactive coil to give a varying electromotive force never to exceed 300 volts. The perfection of the work is influenced by the projection of the abutted pieces in the path of the current, the electro-motive force of the welding current, the end pressure applied to force the abutting ends into each other at welding heat, and the interruption of the current at the proper time.

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* Vol. xlix. pp. 309–310.

† Paper read before the American Institute of Electrical Engineers; *Industries*, vol. viii. p. 618.

The projection of the abutted pieces varies with their diameter. For copper, a projection twice the diameter gives the most economical results, while with steel and iron the projection equals the diameter. For a large class of work—carriage hardware, for instance—the surfaces coming in contact have a light scale, which must be removed by grinding, or overcome by the electro-motive force of the current. In many cases the cleaning is found more expensive than the extra power to force through the scale. For uniform results the end pressure is found to be the most important factor. It varies with the materials, being approximately 1800 lbs. per square inch for steel, 1200 lbs. for iron, and 600 lbs. for copper. The interruption of the current at the completion of the weld is important for all easily fused metals; otherwise a large portion of the conductor on either side, as well as the weld itself, will be melted and torn asunder before any pressure device could follow and bridge the gap.

Electrically Welded Projectiles.—The process of electric welding has been applied to the manufacture of steel projectiles by Lieutenant W. M. Wood, for the purpose of obtaining a hard point with a softer grade of steel for the body. The point is made of a hard steel, and of suitable conical form; to this is welded a tube of mild steel. The butt of the projectile is made of mild steel of somewhat harder quality than the tube, and is shaped to a cup form by hydraulic forging.*

Gun-Lathes.—The *Iron Age* † publishes a series of drawings showing the principal features of the turning and boring lathes for 8 to 12 inch guns which are in course of construction for erection at the Watervliet Arsenal, United States. The drawings are accompanied by detailed descriptions.

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* *Engineering*, vol. l. p. 259.

† Vol. xlvi. pp. 745–748, fifteen illustrations.

Full drawings are also published * of the gun-lathes recently erected at the Washington Navy Yard. A full description is also given. The shrinkage-pit at the yard has been completed, and a Morgan crane has been erected which is capable of dealing with a load of 150 tons.

Large Steel Cannon.—The large cannon made at the Krupp Works, Essen, for the fortifications at Cronstadt has recently been completed. It is of crucible steel, weighs 135 tons, is 40 feet in length in the barrel, and has a calibre of 13½ inches.†

Cleaning Tin and Terne Plates.—A machine devised by Mr. J. Abbot is in extensive and successful use for cleaning the grease from tin and terne plates by passing them automatically through bran after the tinning operation. The plates are fed mechanically to two bran troughs by means of a rack. The troughs are arranged tandem, and consist of segmental cylindrical sections, across the middle of each being journalled a transverse shaft having diametrical arms, the extremities of which are provided with automatic gripping attachments that seize each sheet consecutively, and draw it with a downward drive through the mass of bran. The sheet, being fed in, is embraced by the jaws and drawn through the bran, and, emerging upwards, is released by trip mechanism, and drops into the grip arms of the second trough, which is geared so that its movements properly coincide. The sheet is reversed in its full exposure, so that both sides are thoroughly cleansed. The operation requires no handling, the sheets dropping into an orderly pile at the end of the apparatus much in the same way that a printing press deposits the printed sheets. The machine is so arranged that plates of any size can be worked.‡

Ingot Metal for Bridges.—A new iron bridge is to be built over the River Weichsel, Germany, at a cost of £500,000. Ingot metal will be used in its construction. There will be five spans of 328 feet, and thirteen of 203 feet.§

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* *Iron Age*, vol. xlv. pp. 902-905, fourteen illustrations.

† *Ibid.*, vol. xlv. p. 1083.

‡ *Iron and Coal Trades Review*, vol. xli. p. 466.

§ *Stahl und Eisen*, vol. x. p. 823.

The Cernavoda Bridge.—A new bridge is now in course of construction which will span the Danube in the immediate neighbourhood of Cernavoda, Roumania, about 174 miles from the mouth of the river.* The total length of the new bridge will be 2460 feet; the main span will have a width of 624 feet.'

Basic open-hearth steel will be used, the quality of which is to be as follows:—

Material.	Tensile Strength, Tons per a Square Inch.	Elongation per Cent. on 6·09 Inches.	Limit of Elasticity, Tons per Square Inch.
For sheets and shapes . .	26·7 to 30·5	21 to 16	24
For rivets	24·1 to 27·9	22	...
For girders	34·3 to 37·5	17	...

The test-pieces used in the tensile tests are to be bars each 8·66 inches in length and 0·775 square inch in section. The marks on the bar are to be 7·87 inches apart, and the space between them is to be divided into twenty equal parts, of which the three in the immediate neighbourhood of the point of rupture are not to be taken into consideration when measuring the elongation of the fractured test-piece. If the fracture takes place at either side of the central third of the bar the test is not to be accepted.

The ingot iron sheets and shapes are, as far as possible, to be worked cold. No iron hammers are to be employed, but presses used wherever possible. Where heating is absolutely necessary, this is to be confined to the point which is to be worked; and working at a blue heat, 200° to 300° C., to be carefully avoided.

Wrought Iron Chimneys.—A wrought iron factory chimney has recently been erected at Creusot. Its height is 279 feet, diameter at the base 23 feet, and at the top 7½ feet; the total weight, exclusive of foundations, being 80 tons. The shaft was built in successive rings 4 feet 1 inch high, the thickness varying from $\frac{9}{16}$ inch at the base to ¼ inch at the top. The eight lower rings are lined with fire-brick. A flying scaffold of novel character was used in the erection; it consisted of a central tube 7 inches in diameter, supported by arms on brackets inside the shaft. The upper part of the tube carried jibs which supported an exterior circular platform. The complete scaffold weighed about 4 tons.*

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* *Stahl und Eisen*, vol. x. p. 588.

Mr. R. M. Bancroft † states that a considerable number of wrought iron shafts have been erected during the last twenty years; and previous to the building of this particular shaft, MM. Schneider et Cie., Creusot, had erected a similar one, 197 feet high.

Messrs. Witherow & Gordon, of Pittsburgh, Pennsylvania, have, since 1876, built upwards of thirty wrought iron chimney shafts, varying in height from 100 feet to 190 feet; the latter they constructed for the Cleveland Rolling-Mills, Ohio, in 1881.

Messrs. Francis & Co., Nine Elms Cement Works, Rochester, in 1878 had a wrought iron chimney shaft erected at their works 160 feet high.

In Russia wrought iron chimneys are very common. One built in 1874 at Adeshavo, near the town of Kineshma, is 170 feet high.

At Messrs. Robert Heath & Sons' Ironworks, Tunstall, Staffordshire, there is a wrought iron shaft 75 feet high from the ground line, built up parallel, 6 feet diameter, from bottom to top.

Iron and Steel at the Paris Exhibition.—Mr. F. Lynwood Garrison,‡ the delegate of the Franklin Institute, has drawn up an exhaustive report, covering 114 pages, on the progress of the metallurgical arts as exhibited at the Paris Exhibition in 1889. During the past twenty years the progress in this direction in France has, he believes, been equal to, and in some instances greater than that in any other country in Europe. Although the production of war material has had a most important bearing upon the French metallurgical industries, information relating to it is particularly difficult to obtain. In the manufacture of light and heavy ordnance the French take the first rank, and their present facilities for manufacturing large gun forgings and for rolling armour-plate are, perhaps, greater than those of any country in the world. In the matter of iron and steel shipbuilding the progress has been very rapid. In the improvements of harbours, building of bridges, and other engineering works requiring a large consumption of iron and steel an equal progress has been made. Great advances have also been made in the improvements of the railways. Taken in its entirety, the Paris Exhibition gave a most satisfactory representation of the resources and wealth of the French nation.

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* *The Engineering and Mining Journal*, vol. l. p. 105.

† *Industries*, vol. viii. p. 615.

‡ *Journal of the Franklin Institute*, May to October 1890.

Coming to the details of the report, the author describes, with the aid of twenty-six illustrations, all the main exhibits relating to iron and steel. He does not, however, confine himself to describing the exhibits of the French iron and steel works, but gives descriptive accounts of the works themselves. Amongst these he includes several of the largest works, notably Creusot, which were not represented at the Exhibition.

PHYSICAL PROPERTIES.

Internal Strains in Iron and Steel.—Mr. J. E. Howard,* in describing experiments made at the Watertown Arsenal, Massachusetts, observes that few pieces of structural metal are in a state of internal repose, although not at the time acted upon by the external stress. To measure the extent of such strains involves the cutting up of the metal, in order to allow the strains to assert their presence by changing the form or dimensions of the piece examined. Thus, if it is found that a stress of 30,000 lbs. per square inch will strain a piece of metal one-thousandth part of its length, then the restoration of the metal for a like amount from a state of internal strain indicates that a stress of 30,000 lbs. per square inch had been acting in that part of the metal.

No general method has been discovered whereby the presence of internal strains may be identified and their magnitude defined, except in the manner above indicated, although there are instances, as in the case of piano wires, in which the transverse vibrations indicate the tensile strains in the metal. This case, however, is exceptional, and it does not meet cases of compressive strains, nor when tensile and compressive strains are in close proximity to each other.

A certain electro-motive force is developed when the specimen is strained. Yet this electro-motive force is apparent only when the strains are changing. The causes which introduce internal strains may be known, and the kind, whether tensile or compressive, accurately predicted in certain cases. But beyond this, we are generally compelled to practically destroy the metal for constructive purposes, in order to obtain actual proof of the magnitude of the internal strains.

Internal strains may be beneficial or detrimental, according to their disposition in the metal, their magnitude, and the purposes for which the metal containing them is intended. In the construction of ordnance internal strains may be of valuable application. The metal at the bore of a well-designed gun necessarily endures the widest range of strains, and by the introduction of internal compressive strains of definite amount at the bore, the working powder pressure is largely increased, without exceeding the tensile elastic limit of the metal at the moment of discharge. This result would follow the application of lower pressures were it not for the internal strains purposely introduced. Conversely, in steel rails, axles, and other articles exposed to alternate stresses of tension and compression, internal strains may be very detrimental.

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* *Iron Age*, vol. xlvi. p. 248.

A series of experiments was carried out with some steel cylinders taken from tube forgings of 3·2-inch rifles. The quality of metal in these tubes, as shown by tensile tests, was as follows:—Elastic limit, 51,000 lbs. per square inch; tensile strength, 86,900 lbs. per square inch; elongation in 2 inches, 22 per cent.; contraction of area, 45·7 per cent.; the original diameter of stem being 0·505 inch. Three cylinders were used, all of which had been oil-hardened and annealed, and one of the cylinders had subsequently been oil-hardened, but not annealed.

The method of investigating the strains in these cylinders consisted of establishing on the exposed ends data points defining the extremities of diameters laid off on the concentric rings into which the cylinders were afterwards cut. These rings, when detached, measured about 1 inch long by 0·23 inch thick. The expansion or contraction of the detached rings showed the kind of strain to which they had been subjected in their assembled state, and the stresses corresponding to the released strains were computed, assuming for the purpose a modulus of elasticity of 30,000,000 lbs. per square inch. The application of the same modulus of elasticity to tempered and to annealed metal was justified by the results of earlier experiments upon plain tensile bars. The approximate dimensions of the cylinders were:—Exterior diameter, 6¼ inches; diameter of bore, 2¾ inches, and length nearly 4 inches.

A cylinder examined, which had been rehardened but not re-annealed, after detachment from the tube forging, had therefore been exposed during its last treatment to the direct action of the quenching liquid on all its surfaces, ends, bore, and exterior diameter. The entire surface metal of this cylinder was found in a state of compression; the interior and inaccessible portions must therefore have been in a state of initial tension to balance the compressive strains found. The magnitude of the released compressive strains corresponded to stresses ranging from 12,038 to 47,161 lbs. per square inch. The greatest strains were met with at the corner rings, which themselves were somewhat conical after detachment, showing that the corners were most affected by the quenching bath. The strains referred to pertain to rings taken from each end of the cylinder.

In another cylinder, which had been annealed, the strains were found to be small, showing the annealing process to have been very effective.

Hardening experiments showed that the temperature from which the metal is quenched, as well as the kind of quenching liquid employed, exerts a marked influence upon the density of the metal.

Similar treatment causes both internal strains and changes in density, and these two features would therefore appear to be connected as correlative functions.

As to the persistence of internal strains, it appears logical to believe that strains equal to the elastic limit may continue to exist at any given temperature, after once a state of equilibrium has been reached; that is, after all molecular flow has ceased. It is further believed that whilst molecular flow may range over wide limits of time at different temperatures, still, as touching upon the question of the ultimate endurance of stress, equilibrium is comparatively soon established. This leads to the inference that there is some stress above zero load which the metal will endure for an indefinite period of time, and that it is immaterial whether this stress is the result of internal strains in some parts, or whether it results from external forces.

Other experiments would appear to show that by annealing the elastic limit is lowered as the temperature increases, and with the lowering of the elastic limit follows the removal of some of the strain, an amount nearly proportional to the reduction of elastic limit. It should not be strictly proportional, because the modulus of elasticity diminishes with increase of temperature. Hence it tends to correct a part of the direct effect of the loss in elastic limit.

Further experiments made to determine the influence exerted by hammering, showed that when a steel tube 5·5 inches in length, 8 inches internal, and 15·5 inches external diameter, was struck repeatedly with a 20-ounce hand-hammer, using the round pene, the direct effect was found to consist in the diminution of the density of the zone of metal 0·125 inch or less in thickness, lying next the exterior surface.

The subject of the physical properties of iron and steel, dealt with at the Watertown Arsenal, in the series of papers of which abstracts are given, is so important, and the papers themselves of such interest, that these are well worthy of a much more careful consideration than is possible in the limits of an abstract.

Physical Properties of Iron and Steel at High Temperatures. —Mr. J. E. Howard * gives the results of a lengthened investigation of this question made at the Watertown Arsenal, Massachusetts.

Coefficients of Expansion by Heat.—The test-bars were 35 inches in length, and were exposed to a range of temperature of about 210° F. The steel test-pieces were turned down in the lathe to 1 inch diameter from 1¼-inch hot-rolled bars; the wrought iron and cast iron to 1⅛ inch diameter. The copper bar used as a standard was 1¼ inch in diameter.

There was no marked difference in the rate of expansion of wrought iron, which had been overstrained nearly to its limit of rupture, and the same metal annealed. The coefficients for steel refer to annealed or hot-rolled metal.

The following table shows the results of this series of tests:—

Metal.	Marks.	Chemical Composition.				Coefficient of Expansion.
		C.	Mn.	Si.	* Fe by Difference.	Per Degree F. per Unit of Length.
Wrought iron	...	...	...	...	...	0·0000067302
Steel	1a	0·09	0·11	...	99·80	0·0000067561
Steel	2a	0·20	0·45	...	99·35	0·0000066259
Steel	3a	0·31	0·57	...	99·12	0·0000065149
Steel	4a	0·37	0·70	...	98·93	0·0000066597
Steel	5a	0·51	0·58	0·02	98·89	0·0000066202
Steel	6a	0·57	0·93	0·07	98·43	0·0000063891
Steel	7a	0·71	0·58	0·08	98·63	0·0000064716
Steel	8a	0·81	0·56	0·17	98·46	0·0000062167
Steel	9a	0·89	0·57	0·19	98·35	0·0000062335
Steel	10a*	0·97	0·80	0·28	97·95	0·0000061700
Cast (gun) iron	...	...	...	...	...	0·0000059261
Drawn copper	...	...	...	...	...	0·0000091286

The means of the various tests gave the following results:—

Metal.			Coefficients of Expansion for 1° C.
Weld iron			0·00001211
Steel	carbon	0·09–0·51	0·00001194
	manganese	0·11–0·58	
Steel	carbon	0·57–0·97	0·00001133
	manganese	0·93–0·80	
Cast iron			0·00001067

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* *Iron Age*, vol. xlv. pp. 585–590.

Further experiments were made for the purpose of determining the effect of sudden quenching from a high temperature. Nearly the whole of the bars so treated were more or less shortened in length. By reheating and quenching, the results were much more marked. The coefficient of expansion under rising temperature, influenced by the permanent diminution in length going on simultaneously with the heating, was apparently so low as 0·0000023564 in bar No. 10A. The maximum temperature of the hot bath in this instance was 233·7° F.

When returned to the cold bath all the bars were found shortened, the amounts ranging from 0·0010 to 0·0343 inch, the greater diminution occurring with the high-carbon metal. Returning the bars to the cold bath, and computing the coefficients from the contractions then observed, it was found that bar No. 10A had the coefficient 0·0000072958, and three other bars had coefficients above 0·000007.

Whereas in the annealed bars the coefficients diminish with increase of carbon, the hardened bars, divested of the element of permanent diminution in length, display a decided elevation in this value, reaching a maximum in the high-carbon bars, but with little, if any, gain in the mild steels.

Modulus of Elasticity.—The temperature at which the tests were made varied up to 495° F., the specimens being strained in an oil-bath. The results show that the modulus of elasticity diminishes with an increase of temperature.

Tensile Strength.—The test-pieces were 5 inches in length and 0·798 inch in diameter. They were heated by means of a row of gas-burners in a muffle, and the results show that the tensile strength diminishes as the temperature increases from zero F. until a minimum is reached between 200° and 300°, the minimum point being, as a rule, reached the more quickly the lower the percentage of carbon. When this temperature is exceeded, the tensile strength increases again until a maximum is reached at a point lying between the temperatures 400° and 650° F., the hard steels appearing to attain their maximum strength at a somewhat lower temperature than steel of lower carbon, and to retain their maximum strength over a more limited range of temperature. Cast iron appears to increase slightly in strength up to a temperature of about 900° F., above which temperature the strength rapidly diminishes. The results are given in the form of curves, and these show that steels differing in tensile strength by as much as 90,000 lbs. per square inch when cold, differ but by 10,000 lbs. at the higher temperature. A "blue heat" is equivalent to about the temperature of the maximum tensile strength. Malleable iron shows a similar variation in strength to that shown by steel. The stress on the ruptured section exceeded the tensile strength by upwards of 100 per cent. in the case of mild steel, diminishing to but 11 per cent. with harder metal.

The Elastic Limit.—This appears to steadily diminish with an increase of temperature.

The Reduction of Area at the point of rupture varies with the temperature of the metal.

The contraction of mild and medium hard steel is somewhat less at 400° to 600° than at atmospheric temperature, and within this zone there is a tendency to fracture in an oblique direction across the bar. The hard steels showed substantially the same contraction up to 500°. Above 500° or 600° the contraction increases with increase of temperature, excepting bars 8A, 9A, and 10A, which formed a special group, and displayed a stage of diminished contraction at 1100° to 1200°, until at the highest temperatures some of the specimens drew down almost to points before rupture was complete. The diminished contraction at 400° to 600°, coupled with the tendency to fracture in an oblique shearing direction, are significant features, inasmuch as they harmonise with the brittleness frequently observed in bending tests at these temperatures.

The total *Elongation* is greatest at ordinary temperature.

The interval between the elastic limit and the maximum stress has features of great interest. Several of the different grades of steel show a yield-point at the elastic limit, this period being marked by rapid stretching without increase of stress, and frequently the stretching, once begun, will continue under reduced loads. It rarely happens that yielding of this kind occurs more than once when the test is made at atmospheric temperature. In mild steel this phenomenon has been observed up to about 500°. In hard steel, if present, it occurs at less elevated temperatures. Bars tested at temperatures between 200° and 400° exhibited alternate periods of relaxation and rigidity under increasing stresses, resembling a succession of yield-points, thus giving a zig-zag appearance to the curve representing the tensile test. Observations on the contractile force developed during cooling from high temperature showed that the same kind of behaviour took place. These intervals of relaxation and rigidity occurring under both rising and falling temperature are suggestive of some remarkable change taking place within the metal in this zone of temperature, phenomena conspicuous in a series of tests possessing many remarkable features. After passing this critical stage of seemingly unstable condition, the metal, under higher temperatures, gradually stretches under increasing loads, the extension accelerating in speed as the tensile strength is approached.

The rate of speed of testing was found to greatly affect the results of tests made at high temperatures. The rate of flow under stress was also examined, as was the question of overstraining in the hot, followed by subsequent rupture in the cold, and the specific gravity. The specific gravity of the test-pieces submitted to tensile tests was lowest at the points of rupture.

Iron at Low Temperatures.—A. von Frank * observes that the statement that at a low temperature iron becomes very brittle is not true as far as the temperatures of a European winter are concerned. Here, in mountain districts, iron bridges have often to withstand temperatures of from − 22° to − 25° C. Again, the Arctic explorer Greely showed that the iron implements, musket-barrels, &c., that he took with him on his expedition were perfectly good at the end of the voyage, although the temperature experienced had been as low as − 56° C.

Effect of Cold on Steel.— The results of a number of experiments to determine the effect of low temperatures on hardened and unhardened steel are given by E. Bernardon.† The amount of contraction diminishes with the temperature, but the coefficient of expansion is less in unhardened steel. The limit of elasticity increases, while the elongation and local contraction diminish, with the temperature. The ratio of these factors, low temperatures, to those at higher temperatures is rather greater in the case of unhardened steel. Test-pieces which have been exposed to great cold do not show any marked difference when tested at normal temperatures. Brittleness, as shown by tests under a falling weight, increases more rapidly in the case of unhardened steel than hardened steel. The stiffness of the test-pieces, however, increases with the diminution of temperature. The appearance of the fracture also changes from greyish to a more brilliant grain at low temperatures. The effect of these temperatures, however, ceases as soon as the metal returns to the ordinary temperature.

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* *Praktische Physik*, 1890, p. 185.

† *Revue d'Artillerie*, vol. xxxvi. pp. 485–521.

The effect is also reduced when much work has been put on to the metal.

Influence of Temperature on the Tensile Strength of Iron.—A joint committee appointed in 1886 by the Berlin Society of Arts and the German Iron and Steel Institute to study the influence of temperature on the tensile strength of ingot iron has recently presented its report. A. Martens,* a member of the committee, observes that the older experiments on the subject were not concordant, nor were they of a sufficiently extended character.

The experiments instituted by the committee related to four kinds of ingot metal, with increasing percentages of carbon, and varying as follows in tensile strength:—22·86, 26·67, 30·48, and 34·28 tons per square inch. The first class was of the character of rivet iron.

The bars were tested at temperatures not exceeding 200° C. by surrounding them with a paraffin bath, a metal bath—tin and lead—being used for temperatures from to 200° to 600° C. Temperatures from the freezing-point to − 20° C. were obtained by the use of freezing-mixtures. The determination of the temperature of the bath was effected at temperatures below 400° by the Geissler nitrogen-filled mercury thermometer, an air thermometer being used for higher temperatures. The results of the experiments are shown in the form of curves. In each of the classes examined the tensile strength was higher at − 20° than it was at + 20°, but when this temperature was exceeded, it rose again, reaching a maximum at between 200° and 300°, and then diminishing till a minimum was reached at the highest temperature examined.

These results relate only to the three first-mentioned classes of steel, the material submitted to the committee not having been of such a character as to enable them to obtain the harder class of steel desired. The examination of this material was therefore deferred.

Examined as a whole, the experiments point to the existence of one main critical temperature below 600° C., and situated at or about 300°, as exerting a maximum influence on the mechanical properties of steel.†

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* *Stahl und Eisen*, vol. x. pp. 843–853.

† *Note by Abstractors.*—This point appears to coincide with that to which attention has been drawn by Barus and Strouhal, and by Osmond. Compare Osmond's paper, *Journal of the Iron and Steel Institute*, 1890, No. I. p. 54.

Effect of Temperature on Tensile Strength.—According to A. le Chatelier,* all metals may be broken by a constant tensile stress above a certain temperature, the rate of extension depending on the load. This effect is produced in all metals at all temperatures with loads that produce permanent elongation. The results of a number of experiments are given, and the following conclusions are advanced :—With constant temperature the deformation under a given load has a decreasing value tending towards equilibrium. The deformation increases more rapidly than the loads, while the stress increases and the strain diminishes with the speed of loading. Deformation under shock is inversely proportional to the shock. Under an increase in temperature the deformation increases and the resistance decreases. Cast iron at 15° C. can support the following loads without breaking for the given times :—

Time in Minutes.	Load in Tons per Square Inch.
½	25·21
1	24·63
5	23·87
15	23·49
60	22·86

The Cubic Compression of Steel.—Mr. J. E. Howard† publishes the results of a further series of tests made at the Watertown Arsenal, Massachusetts, and relating to the cubic compression, cold flow, and crushing strength of iron and steel. The test-bars used for cold flow and compressive resistance were short cylinders 2·5 diameters long, loaded axially without lateral support, increasing the stress until a well-defined ultimate resistance was reached, or until the metal was greatly distorted. In the series relating to cubic compression cylindrical specimens were employed, each about 5·5 inches in length and 0·75 inch in diameter.

Experiments were made with ten grades of steel with the percentage of carbon varying from 0·09 to 0·97 per cent. The results are shown in the accompanying table :—

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* *Comptes Rendus de l'Académie des Sciences*, vol. cx. pp. 705–708.

† *Iron Age*, vol. xlvi. p. 692.

Tabulation of Results upon Cold Flow and Crushing Strength.—Original Dimensions of Specimens, 2 *inches long,* 0·798 *inch diameter.*

Kind of Metal.	Reduced Length.	Concurrent Compressive Resistance, per Square Inch.	Ultimate Compressive Resistance, per Square Inch.	Maximum Elongation of Surface Metal.	Tensile Stress on Ruptured Section, per Square Inch.
	Inches.	Lbs.	Lbs.	Per cent.	Lbs.
Steel 0·09 carbon .	1·24 0·83	84,030 85,470	85,580	72·8	106,434
Steel 0·20 carbon .	1·31 0·83	100,120 101,890	105,520	75·6	113,704
Steel 0·31 carbon .	1·26 0·95	115,150 115,560	116,790	80·5	126,640
Steel 0·37 carbon .	1·26 0·88	121,070 121,850	121,850	72·1	134,600
Steel 0·51 carbon .	1·425 0·89	131,760 131,900	133,480	95·5	152,380
Steel 0·57 carbon .	1·245 0·965	156,630 156,640	157,100	58·8	134,880
Steel 0·71 carbon .	1·34 0·89	156,250 156,640	156,800	59·1	151,510
Steel 0·81 carbon .	1·465 1·20	194,240 196,300	196,300	54·5	158,140
Steel 0·89 carbon .	1·60 0·93	181,100 183,250	188,110	51·3	147,860
Steel 0·97 carbon .	1·33 1·05	192,550 193,090	193,090	45·6	161,910
Cast iron . . .	1·825	96,320	96,320	9·6	...
Wrought iron, not annealed * . .	1·545 1·21	90,630 90,290	91,500	43·2	...
Wrought iron, annealed * . .	1·555 1·18	91,600 93,610	93,610	51·4	...

Under free compressive stresses the specimens began to bulge laterally when the elastic limit was passed, and the stress per square inch increased for a time thereafter, while the shortening in length and increase in diameter continued. But while the gross load was gradually increased to the end of the test, a period was reached when the stresses per square inch on the sectional area, as it existed, ceased to increase, and for an interval the flow was continuous, with practically no increase of stress. This period marked the ultimate compressive resistance of the metal.

An examination of the tensile and compressive tests does not show that any marked difference in tensile strength resulted from the cubic compression. Neither was it found that the ductility of the metal, as indicated by the elongation and contraction, was materially changed by the treatment.

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* These specimens came from a ruptured tensile specimen. It was desired to learn whether any decided difference existed between an annealed bar and one which had been overstrained by the opposite kind of stress.

Under the ordinary free tests by tension or compression certain stresses—those below the elastic limit—do not cause any sensible change in physical properties. Stresses exceeding that limit ordinarily bring about a series of phenomena which culminate in rupture or disintegration of the material. Under cubic compression no pressures were reached which gave evidence of such a tendency in the ultimate result as that caused when flow of the metal occurred.

In other words, whilst it is probable that there is a restricted molecular orbit represented by the elastic limits of tension and compression, and that these orbits may be disturbed and thrown into new positions by loads exceeding the elastic limit, in the case of cubic compression sufficiently high pressures to sensibly disturb them were not employed in the experiments; nor is it certain whether by such means a limit can be reached when they may be interfered with.

The Physical Properties of Cast Iron.—A. Ledebur,* in discussing recent researches on this subject, and more especially those of Mr. J. B. Johnson and Mr. W. J. Keep, points out that it has been shown that the modulus of elasticity diminishes steadily with an increasing load. The ratio of the bending strength to the tensile strength is usually 2 : 1.

With regard to the influence of impurities in the metal on its physical properties, phosphorus lowers the melting point and diminishes the tendency to the formation of blow-holes. It diminishes the tensile strength, and does not greatly increase its hardness.

The Crystalline Form of Iron.—S. Stein † refers to a statement on this subject published by Wöhler in 1833, who came to the conclusion that iron was cubical, having observed both cubes and octahedra. These octahedra contained 2·5 per cent. of silicon.

The author observes that when iron is pure, the form in which it crystallises is that of a cube. It is probable that this structural arrangement plays a very important part in the varying degrees of weldability shown by different samples of iron, or on differently treating the same bar.

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* *Stahl und Eisen*, vol. x. p. 602.

† *Ibid.*, p. 821.

The Effect of Phosphorus on Iron.—A. Ledebur * observes that the dissimilar action of equal percentages of phosphorus in different samples of iron has long been a matter to which attention has been paid, without even now being definitely settled.

The influence of phosphorus on steel is easier to understand than is the fact, to which attention has frequently been drawn, that weld iron, as a rule, is less affected by the presence of phosphorus than is ingot iron of similar composition. Weld iron containing 0·4 per cent. of phosphorus may be a perfectly satisfactory metal, and Karsten even places the limit at which phosphorus begins to deleteriously affect weld iron at 0·5 per cent. On the other hand, 0·2 per cent. of phosphorus in ingot iron will make it distinctly cold-short, and all the better varieties, even those containing but little carbon, are found to contain less than 0·1 per cent. of phosphorus.

The author points out, however, that the percentage of phosphorus usually given as occurring in weld iron fails to take into account the presence of entangled slag. The author has made numerous determinations of the slag present in such iron, and he has found this to vary from 0·17 per cent. to as much as 3 per cent. in different varieties of weld iron. In the poorer varieties of puddled bars the percentage is probably about 2. It is inaccurate, too, to assume that the composition of the slag in the metal is identical with that of the slag remaining in the furnace immediately after the metal had been removed, the following being some partial analyses :—

	Slag in Furnace.			Slag in Metal.		
	P.	Fe.	SiO_2.	P.	Fe.	SiO_2.
I.	1·90	56·04	14·10	2·06	57·76	13·38
II.	2·85	58·77	...	2·92	59·05	...
III.	2·76	55·20	13·25	3·32	56·19	12·82

Assuming that the average percentage of slag in ordinary weld iron is 2 per cent., and that the percentage of phosphorus in this slag is 3 per cent., the percentage of phosphorus inaccurately ascribed to the iron is thus as much as 0·06 per cent.

The author next proceeds to discuss the question whether ingot metal really is more affected by phosphorus than is weld iron, or whether this is merely a historical fiction. At the time when this belief originated it was absolutely impossible to manufacture an ingot iron at all similar to weld iron. Indeed, steel with over 0·3 per cent. of carbon, and still higher percentages of manganese, was all that could be produced. It was the introduction of the basic process which enabled a soft metal to be produced, as low in phosphorus as a weld iron made from the purest varieties of pig iron; the result being that, owing partly to the presence of slag in the weld iron, such an ingot metal is far the better of the two, as far as its mechanical properties are concerned. The author appears to doubt the statement that a considerable percentage of phosphorus may be present in metal made by the Clapp-Griffith process without any very bad results actually ensuing; and he observes that, as yet, all that has been stated in favour of this belief amounts to no more than this: that whilst Clapp-Griffith metal high in phosphorus may be adapted for certain uses, as far as toughness is concerned it is much behind ingot metal low in phosphorus made by other methods. Even in the United States, the author adds in conclusion, the fervent admiration which was at first expressed for such Bessemer methods on a small scale appears now to be rapidly diminishing.

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* *Stahl und Eisen*, vol. x. pp. 513–516.

The Molecular Constitution of Steel.—A. Gouvy * observes that, with the practical disappearance of the older methods for the manufacture of iron in favour of the more modern ingot methods, the older questions—such, for instance, as the elimination of slag from the bloom—have, in turn, given place to others which are of greater technical importance now. These older questions were based more particularly on empirical reasons, whilst the modern ones have a more scientific basis. By no means the least among these is the question of molecular constitution. Analysis, it is true, still plays a very important part when it is desired to choose an ore for the manufacture of steel of a certain quality, but it is no longer the sole matter considered. Physical questions, such as those relating to casting, forging, hardening, heating, &c., are now receiving much greater attention, and the results of modern theoretical researches are beginning to play a very important part in changing methods of manipulation. Such studies, therefore, formerly of mere theoretical interest, are now frequently of great practical importance.

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* *Stahl und Eisen*, vol. x. pp. 607–611.

The author then proceeds to discuss at some length the experiments of Osmond, Evrard, Tchernoff, and others, accounts of which have already appeared in this *Journal*, and, in conclusion, describes the results obtained in the measurement of high temperatures by Messrs. Mesuré and Nouel by the aid of their pyrometer.*

The Flow of Metals.—Mr. P. Kreuzpointer,† in discussing this subject, draws attention to the published work of Tresca, Roberts-Austen, Martens, Kirsch, and others. The author points out that the structure of the material greatly influences the rate of flow, steel with a distinct granular structure flowing less readily than steel with a "mushy" structure, though both may show almost identical results as to tensile strength and elongation when submitted to tensile tests. Various facts are referred to as practical evidence that metals flow under the influence of stress, the influence of the size and shape of a test-piece being also discussed; the author observing that the degree of ductility and elongation of a metal depends on the rate of flow of that metal. To be of good quality the metal should flow uniformly under a regularly increasing load.

With reference to the elasticity possessed by steel, the author refers to a remarkable instance in which a steel test-piece of spring steel 10 inches in length between the fillets and 0·389 square inch in section was fitted before testing with a micrometer screw and electric bells. On pulling this test-piece with the hands and then letting go, the bells were found to ring, thus proving that a force so slight as the above was sufficient to cause an elongation of the bar.

If the stress applied exceeds the elastic limit, the metal begins to flow perceptibly. It is the rate of this flow, expressed in percentage of elongation, which is usually taken as representing the ductility of the metal.

Tests of Iron and Steel.—In an exhaustive report, covering 159 pages, prepared for the International Congress on Applied Mechanics, C. Cornut ‡ discusses the methods of testing iron and steel in vogue, and urges the necessity of introducing a certain degree of uniformity in the methods employed, and of choosing common units for expressing the results. Further, he points out the desirability of starting laboratories of applied mechanics in connection with technical high schools. These views were put in the form of resolutions, and passed unanimously by the Congress.

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* *Journal of the Iron and Steel Institute*, 1889, No. I. p. 251.

† *Iron Age*, vol. xlv. p. 948; xlvi. pp. 2, 126.

‡ *Congrès International de Mécanique Appliquée. Conférence sur les Essais des Fers et des Aciers et les Laboratories de Mécanique.* Lille, 1890.

As far back as 1882, at the Vienna meeting of the Iron and Steel Institute, the formation of an International Commission on this subject was suggested.*

Testing of Iron and Steel.—The mechanical tests required by the German Lloyd for the weld iron and ingot metal used in ship construction are described in *Stahl und Eisen.*† Weld iron is divided into two classes, which are required to show:—

	First Quality Metal.		Second Quality Metal.	
	Tensile Strength.	Elongation on 7·87 Ins.	Tensile Strength.	Elongation on 7·87 Ins.
	Tons per Sq. Inch.	Per Cent.	Tons per Sq. Inch.	Per Cent.
Along the fibre . .	22·22	7	20·00	4
Across the fibre (plates) .	18·09	5	17·46	2

This metal has then to be submitted to bending tests through certain numbers of degrees, both in the hot and when cold. Angle iron is to be submitted to a forging test, and rivets to bending, upsetting hot to one-third the height, and punching, after flattening, the diameter of the hole to be about equal to the diameter of the rivet. No cracks are allowed.

The tensile strength of ingot metal used for shipbuilding may vary within the following limits, both along and across the fibre:—26·03 to 31·11 tons per square inch, with an elongation of not less than 20 per cent. on a length of 7·87 inches. If ingot metal is used having a strength less than the above, the thickness of the metal must be proportionately increased.

The tensile strength of weld iron rivets shall be at least 23·5 tons per square inch, with an elongation of 15 per cent., the test-pieces being of the same length as the above.

The Measurement of Test-Pieces.—Mr. J. H. Wicksteed ‡ suggests a new method of measurement of test-samples. When a bar of metal is stretched with a longitudinal pull, it first extends generally throughout the whole of its free length; after which, especially in the best iron and mild steel, it extends locally about the place of final fracture. The general extension continues so long as the bar offers increasing resistance to the pull, and from the end of that stage to final fracture the extension is local. This general extension is unaffected by the shape or proportions of the specimen, and may be correctly expressed in units of its own length. The local extension bears no relation to the length of the specimen, and should therefore be expressed in standard units of length. The usual practice at present is to measure the total extension, and to express it in percentage of the original length of the specimen; but this practice makes it difficult to draw correct comparisons of ductility between different experiments, unless the specimens have all been made to the same pattern. It also prevents the value of the material being discriminated as between capacity for contraction and the capacity for stretching without loss of strength. The author describes a method for separating the measurements of the general and the local extensions, and recommends a column in test reports of "per cent. general extension," leaving the present column of "per cent. contraction of area" to record the capacity for stricture, and also leaving the present column of total extension in inches, from which the local extension can be deduced by subtracting the recorded general extension from the total, as measured after the sample is broken.

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* *Journal of the Iron and Steel Institute*, 1882, p. 497.

† Vol. x. pp. 716–719.

‡ Paper read before the British Association, Leeds meeting.

Measuring Strains within the Elastic Limit.—M. le Chatelier* describes an apparatus for measuring strains within the elastic limit, especially applicable for testing the alterations of length in members of iron bridges. The alteration of length is changed into the movement of a diaphragm of large area, acting on a vessel full of liquid, with which is connected a tube of small section. Two plates are fixed to the member; one carries the diaphragm device, and the other carries the rod which operates the diaphragm. These plates are screwed to instead of being clamped to the member. The change of volume in the vessel by pulling or pushing in or out the diaphragm is largely magnified by the rise or fall of the column of liquid in the tube. By calibrating this, and by using a suitable distance between the centres, any desired delicacy in the measurement can be obtained.

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* *Annales des Ponts et Chaussées*, 1890, p. 855; one plate.

A Large Testing-Machine.—A testing-machine recently completed by the Phœnix Iron Company, of Pennsylvania, is said to be the largest ever built. It is designed to test full-size bridge members up to 55 feet in length, and with loads up to 2,000,000 lbs., either in tension or compression. Water-pressure of 720 lbs. per square inch is applied to a cylinder 5 feet 6 inches in diameter and 5 feet stroke. The general style of construction is similar to the machine at the Union Bridge Works at Athens, Pennsylvania. The cylinder is of cast steel, and without the heads weighs 28,000 lbs.; the other parts, cross-heads, &c., are correspondingly massive.*

Testing-Machine.—An illustration is given in the *Engineer* † of a testing-machine designed to carry out all the latest improvements approved of by Professor Kennedy. The specimen is horizontal, about 4 feet from the floor, and the framework does not interrupt the clear horizontal view of the test-piece. The scale of the steelyard is visible from the same point of view as the specimen, and is at about the same level as the observer's eyes. The handles for adjusting the poise and regulating the admission of water to the straining cylinder are within easy reach of the hands while standing at the best point of view for observing the specimen and the steelyard. Finally, the poise weight is made in several parts, so that its travel along the steelyard, and the fineness of observation of its position, may be approximately equal for all specimens of ordinary dimensions.

The machine is of 50 tons capacity, and will take struts up to 11 feet long and ties up to 8 feet long. The ram stroke is 18 inches. Transverse tests on pieces 5 feet between supports can be made, and also tension tests on specimens up to $1\frac{1}{8}$ inch in diameter, with a twisting moment of 20,000 inch lbs. The machine stands in a space 20 feet long, and is self-contained. The straining cylinder and the lever system are both placed at the same end of the bed, and this arrangement will reduce the wear on the knife-edges due to the rebound when the specimen breaks.

Crane Chains.—Mr. C. S. Dutton ‡ gives his experiences with crane chains, and illustrates several broken links, some of which were broken purposely to show the quality of the metal. One chain broke twice in the first month of its use, while another only broke twice, or perhaps three times, in fifteen years. The crystallisation theory will hardly account for this, although the fractures of the broken links present the same appearance, and are just such as are attributed to that theory. The explanation is, that the iron is cold-short and totally unfit for use. The author thinks that the crystallisation theory is a delusion, as he does not believe that a crane chain ever received usage sufficient to produce such an effect. The only way to obtain a good chain is to have the material and workmanship properly inspected. In the discussion it was shown that the iron changed in character owing to the work done on it. A metal with a tensile strength of 51,000 to 56,000 lbs., and 25 to 30 per cent. elongation in 8 inches, will be fibrous after rolling, although it is cold-short; yet it may be precisely of that quality which, when subjected to heating and quenching, will become granular and crystalline. Especially will this be so in the case of chain links, which have to be heated, reheated, hammered, and welded. There would appear to be no such thing as gradual crystallisation. The best test is to subject the metal to rough treatment, similar to what it would experience in its destined use, and then determine the effect on the material.

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* *Industries*, vol. viii. p. 583.

† Vol. lxx. p. 54, illustrations; *Engineering*, vol. l. p. 304, illustrations.

‡ Paper read before the American Society of Mechanical Engineers, through *Engineering*, vol. l. p. 21.

The Schiseophone.—This instrument* is a modification of Professor Hughes' induction balance, and is intended to be used for the detection of flaws in rails and other articles. A core is reciprocated longitudinally within a coil and caused to strike the object. A continuous current from a battery is sent through this coil, which is connected with one of the coils in the induction balance. The other coil on the balance is adjusted to reduce or abolish the sound in the telephone. When the core strikes the object near a flaw the difference of the quality of the sound is readily detected. This instrument, according to *La Nature,* has been successfully used by the Chemin du Fer du Nord.

The Measure of Hardness.—Professor Trouton † proposes a coefficient of abrasion as an absolute measure of hardness. Two cylinders are formed of the respective materials, and are revolved against one another for a definite time and under a definite pressure. The abraded material is weighed, and its amount gives data for calculation of the hardness.

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* *Engineering and Mining Journal,* vol. l. p. 249.

† Paper read before the British Association at Leeds, September 1890.

Manganese Steel and Ingot Metal.—L. Campredon [*] discusses the physical properties of manganese steel. In the case of some tensile tests made at the Saint-Chamond Steelworks the following results were obtained:—

Sample.	Tensile Strength.	Elongation on 3·15 Inches.
	Tons per Square Inch.	Per Cent.
Direct from the forge . . .	51·60	1·25
Plunged in oil from a red heat . .	51·36	18·90
Hardened from a yellow heat in water	57·90	35·00
Hardened from a yellow heat in a freezing mixture	67·31	51·80

The metal contained:—

Carbon.	Manganese.
1·36	13·9

The test-pieces had a useful length of 3·15 inches. They were 0·31 inch in diameter.

Discussing the influence of plunging in water from an elevated temperature on very soft ingot iron, the author observes that, although the actual degree of hardness is not increased, this is the case as regards the tensile strength, as will be seen from the following table, showing the results of tensile tests of hardened bars of ingot metal having the composition:—

C.	Si.	S.	P.	Mn.
0·10	0·02	0·05	0·05	0·40

Sample.	Tensile Strength.	Elongation.
	Tons per Square Inch.	Per Cent.
Annealed	25·71	30·5
Hardened from a cherry red . . .	31·75	20·0
Hardened from a yellow heat . .	39·05	11·5
Hardened from a white heat . . .	33·33	19·0

The experiments thus showed a limit of hardening to exist at a temperature somewhere between a yellow and a white heat.[†]

The higher is the percentage of manganese the greater is the tensile strength, as is seen from the following examples of basic Bessemer steel:—

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[*] *Le Génie Civil*, vol. xvii.

[†] Compare paper by E. J. Ball, *Journal of the Iron and Steel Institute*, 1890, No. I. p. 89.

Sample.	Tensile Strength.	Elongation.	Composition.		
			C.	P.	Mn.
	Tons per Square Inch.	Per Cent.			
Annealed	22·86	32	0·100	0·035	0·250
Annealed	27·94	29	0·100	0·040	0·500
Hardened	29·21	28	0·100	0·035	0·250
Hardened	41·27	14	0·100	0·040	0·500

The effect of hardening and annealing on certain alloys of ferromanganese and copper is considerable, according to Mr. E. L. Nichols,* as the temperature coefficients of high resistance samples change in some cases from negative to positive values after annealing.

Magnetic Properties of Manganese Steel.—Drillings of manganese steel containing 25 per cent. or less of manganese are noticed to have magnetic properties after having been heated. Mr. L. T. O'Shea † ascribes this to oxidation, which causes the formation of a magnetic oxide of iron. When this oxidised metal is reduced by heating it in hydrogen, the drillings become powerfully magnetic, probably because the manganese iron alloy has been destroyed, and metallic iron and an oxide of manganese have been produced. The author rejects a dissociation theory advanced by Professor Barrett. Filings showed magnetism after heating, because the oxide adhered; but in the case of large masses the oxide scaled off, and the metal was not magnetic.

Testing the Magnetic Properties of Iron.—Mr. J. Swinburne and Mr. W. F. Bourne ‡ describe their method of testing iron for its magnetic permeability and loss by hysteresis. The various samples are obtained in the form of wire, and made up into rings of uniform dimensions, the specific gravity and resistance being first measured. The rings are wound with suitable primary and secondary coils, in which the inducing and induced currents circulate. Full details are given of the arrangements of the circuits and measuring instruments, with the methods of taking the observations and the corrections applied. A number of curves are given to show the loss in the sample.

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* *American Journal of Science*, 1890, vol. xxxix. p. 471.

† Paper read before the British Association at Leeds, September 1890.

‡ Paper read before the British Association, Section A, at Leeds, September 1890; through the *Electrician*, vol. xxv. pp. 648–650.

The Villari Critical Points in Iron.—Mr. H. Tomlinson * has further investigated the effect of a change of temperature on the Villari critical points, using the same methods as previously described.†

Experiments were made at various temperatures up to 285° C., the temperature being measured by the resistance of a platinum wire, whose temperature coefficient was carefully determined. The following table shows some of the results obtained with a well-annealed iron wire, 1 millimetre in diameter, which had been repeatedly heated up to 300° C., and cooled to the temperature of the room, until the temporary permeability with various loads attained constant values at both temperatures :—

Magnetising Force in C.G.S. Units.	Load in Kilogrammes for which Permeability is the same as for Unloaded Wire at the Temperature :—				
	12° C.	76° C.	167° C.	244° C.	285° C.
2·84	4·7	5·0	5·3 and 12	5·7 and 10	none
3·70	2·5	3·2	3·6	4·2 and 11·5	4·7 and 9·9
4·80	1·8	2·5	2·7	...	3·1 and 12·3
7·69	none	none	none	none	none
10·40	,,	,,	,,	,,	,,
15·32	,,	,,	,,	,,	,,

Curves from which these numbers were obtained are given in the paper, and in these the load in kilogrammes and the percentage change of temporary permeability are plotted. From the curves and table, it will be seen that if the first points in which the curves cut the load-line be considered, then, at all temperatures, the Villari values increase as the load decreases. If, however, the second points be taken, the critical values increase both with load and temperature. In both cases the Villari value is increased by rise of temperature. From the curves, it follows that rise of temperature reduces the total variation of permeability that can be produced by loading. A table showing the temporary permeability of the unloaded wire at the various temperatures accompanies the paper.

Steel for Permanent Magnets.—Mr. W. H. Preece,‡ in order to confirm statements previously made § by him, has carried out a series of experiments on various kinds of steel for permanent magnets. A magnetometric method was employed, and all the test-pieces were 10 centimetres long by 1 centimetre square. All the English specimens were hardened in water; some of the French specimens were already hardened when received; others were hardened in water or mercury. The mean induction of each kind is given, and a fully tabulated statement of the experiments is appended. The capabilities of steel seems to depend more on the method employed for hardening it than on the method of magnetisation used.

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* *Proceedings of the Physical Society*, June 6, 1890.

† *Journal of the Iron and Steel Institute*, 1890, No. I. p. 353.

‡ Paper read before the British Association at Leeds, September 1890; through *The Electrician*, vol. xxv. pp. 546–549.

§ *Journal of the Iron and Steel Institute*, 1890, No. I. p. 352.

Pressure Used in Drilling Cast Iron.—Professor Breckenridge,[*] of the University at Lehigh, has made several experiments with a view to ascertain the pressure required to drill through cast iron. A cylinder was filled with oil and provided with a pump piston 10 square inches in area, to which was attached the piece to be perforated. The cylinder was also fitted with a manometer, and with the boring-machine was connected a Watt indicator, by means of which diagrams could be obtained, showing the changes of the pressure transmitted to the oil. Drills of $\frac{1}{4}$ inch diameter were found to exercise a pressure of 399 lbs., while for drills of $\frac{1}{2}$, $\frac{3}{4}$, 1, and $1\frac{1}{4}$ inch diameter the corresponding pressures rose to 897, 1097, 1446, and 1796 lbs.

Steel for Boiler-Plate.—At a meeting held at Stuttgart, modified tests were decided on for material to be used in boiler construction.[†] Particular attention is drawn to the fact that in making the tensile tests the load is to be applied gradually, and great care to be taken to avoid jerks, the added weight to become smaller and smaller as the breaking point is approached. The testing-machines employed are to be retested at least once every three months.

Boiler-Plates.—At the third convention of the American Boiler Manufacturers' Association,[‡] held at New York in July, a long discussion took place on testing steel boiler-plates at the works where they were made. Specifications for the material have already been given,[§] but no method of inspection had been determined upon.

Comparative Value of Boiler-Plates.—A large number of experiments have been made at the Royal Testing Institute, Berlin,* with a view to ascertain the comparative value, for boiler-plate purposes, of metal made by the basic Bessemer and basic open-hearth processes and of weld iron.

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[*] *Le Génie Civil*, vol. xvii.

[†] *Stahl und Eisen*, vol. x. p. 879.

[‡] Through the *Engineering and Mining Journal*, vol. l. p. 12.

[§] *Journal of the Iron and Steel Institute*, 1890, No. I. p. 346.

The composition of the open-hearth metal tested was as follows:—

Carbon.	Manganese.	Phosphorus.	Sulphur.
0·115	0·360	0·025	0·051

The composition of the basic Bessemer metal and of the weld iron is not given, and the chemical composition of the samples tested being different, the tests were not really comparative. It would appear, however, that the weld iron was the least suitable of the metals tested, for the desired purpose, and the basic Bessemer steel the best, the open-hearth metal having been too soft, though its quality was excellent.

The influence of hardening was unexpectedly much more marked in the case of the open-hearth metal than in that of the basic Bessemer iron, probably owing to the latter containing a smaller percentage of silicon.

On both the open-hearth and Bessemer metal the detrimental influence of a blue heat could be observed—350° to 400° C.

Pitting of Boiler-Plates.—Mr. T. P. B. Warren,† in the course of some observations on the pitting of boiler-plates, notes that when the skin or surface of a rolled plate is removed, that part rusts more readily than the untouched surface. This is ascribed to the altered electrical relations of the parts, one being more electro-positive than the other. Pitting of the plates can be explained in the same way. The only remedy is to thoroughly remove the skin all over, and to maintain the whole surface of the boiler in an electro-negative condition by the use of zinc.

Armour-Plate Trials.—Full details are given by Captain De Labouret‡ of some experiments with self-registering projectiles on armour-plates. These projectiles are hollow, and contain a tuning-fork device which registers the time of passage through the plate, and thereby gives data for calculating the resistances. In one case the resistance was 1900 tons shortly after impact; it then fell to 550 tons, but increased again to 2190 tons when about half-way through the plate. After this the resistance again decreased, but gave a third maximum of minor importance. This behaviour is explained by the theory that the local displacement of the material of the plate causes the first maximum; then the plate shifts as a whole, causing the first minimum resistance. The next maximum is caused by the projectile punching a disc from the plate, and then the resistance of the sand backing to the projectile before it has passed completely through the plate gives rise to the last and minor increase of resistance.

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* Through *Stahl und Eisen*, vol. x. pp. 526–534.

† *Chemical News*, vol. lxi.

‡ *Mémories de l'Artillerie de la Marine*, vol. xviii. p. 279.

A plate made at Creusot for the *Chilian* armour-clad has been officially tested. Chilled cast iron projectiles and a 6·4-inch gun were used, and the striking velocity in the three tests was 1463, 1459, and 1564 foot-seconds respectively. The plate measured 18·63 by 6·75 feet, and was of trapezoidal section 8·07 inches thick at the upper edge, and 5·31 at the lower. After fire, the plate presented three slight cracks only.*

The results of the tests made on foreign armour-plates at the Annapolis proving-grounds on September 18, by the United States Naval Board, are of considerable interest.

The plates were three in number—a Schneider (Creusot) all-steel plate, a Schneider nickel-steel plate containing between 3 and 5 per cent. of nickel, and a Cammell (Sheffield) compound plate. This latter is constructed of two sections, the steel face, which comprises one-third of its thickness, being welded on to a wrought iron backing. All were 10½ inches thick. The gun used was a modern high-powered 6-inch rifle, constructed expressly for the trial, 35 calibres (17½ feet) in length. The 100-lb. projectiles used were manufactured in Unieux, France. They were made of forged steel, with points of chrome steel, and were 17 inches long. The initial velocity, using 44½ lbs. of powder, with a chamber pressure of 15 tons to the square inch, was 2075 feet per second.

Four shots were fired at different points on each target. The Schneider all-steel plate was penetrated by each shot, but in no case was it cracked. One of the shots was embedded, two rebounded, and the fourth was broken, a portion remaining in the plate. The projectiles all penetrated the nickel-steel plate, with almost the same results which attended the tests of the all-steel plate. The Cammell composition plate was shown to be utterly incapable of standing the fire. The first shot went through the plate and into 11 inches of the backing, splintering the face around the point of entrance in a very irregular manner, and scattering fragments.

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* *The Engineering and Mining Journal*, vol. l. p. 314.

The second shot had similar results, and, in addition, badly cracked the plate. The third shot penetrated the plate and iron backing, setting fire to the wooden stays and causing additional cracking. The fourth shot passed through the plate and backing, causing the steel face to peel off like wood veneering.

In these tests the projectiles proved equal to the demands made upon them; consequently the comparative tests of the armour were complete. It was expected that, under the conditions, the projectiles would pierce all the plates, and the results shown by the two Schneider plates are highly satisfactory.*

Steel Rivets.—Mr. H. C. Torrance † gives the following results of tests made by the United States Government of the shearing and tensile strength of forty-five steel rivets. The rivets were driven hot and the shearing tests made in single shear. The results were as follows:—

	Tensile Tests.			Shearing Tests.			
	Average Diameter of Specimen in Inches.	Average Tensile Strength per Square Inch in Lbs.	Average Elongation in 8 Inches, per Cent.	Nominal Diameter of Rivet in Inches.	Average Shearing Strength per Square Inch in Lbs.	Number of Tests.	Shearing Strength per Cent. of Tensile Strength.
A	0·624	51,660	31·12	5/8	41,800	9	81
B	0·616	55,925	29·94	5/8	57,963	6	104
C	0·753	58,573	29·56	3/4	47,983	6	82
D	0·756	60,250	29·75	3/4	52,248	6	87
E	0·869	56,370	29·37	7/8	50,601	6	90
F	1·113	56,510	31·17	1 1/8	57,177	6	101
G	1·246	55,390	30·60	1 1/4	49,004	6	88

The sets marked B and F may have been hammered at a low heat, which would account for the abnormal results. Omitting these figures, the shearing strength averages 85·6 per cent. of the tensile strength.

The Government requires that boiler rivets in longitudinal seams shall have a tensile strength of 58,000 to 67,000 lbs., and an elongation of not less than 26 per cent. in 8 inches. For other seams, the tensile strength is to be 50,000 to 58,000 lbs., with an elongation of not less than 30 per cent. They shall be capable of being flattened out, when cold, under the hammer to half their diameter, and, when hot, to one-third their diameter without cracks or flaws. The steel must be made by the open-hearth or Clapp-Griffith process, and must not contain more than 0·035 per cent. of phosphorus or 0·04 per cent. of sulphur.

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* *Engineerng and Mining Journal*, vol. l. p. 330. See also *Industries*, vol. ix. p. 352.

† Paper read before the American Boiler Manufacturers' Association, July 2, 1890.

Tests of the two kinds of rivet steel mentioned gave :—

No. of tests	20	12
Tensile strength, lbs. per square inch .	51,230–54,100	59,100–61,850
Elastic limit, lbs. per square inch .	31,050–33,190	32,080–33,070
Elongation in 8 inches, per cent.. .	30·5–35·25	28·5–31·75
Carbon, per cent..	0·11–0·14	0·16–0·18
Phosphorus	0·027–0·029	0·03
Sulphur	0·033–0·035	0·033–0·035

The safest steel rivets are those of lowest tensile strength, since they are less likely to be damaged by hammering or to break under the concussive and vibratory strains to which they are subjected in practice.

Rails.—Mr. C. P. Sandberg* considers the question of steel rails from a chemical and a mechanical standpoint, and deals with the conclusions which were arrived at in the International Railway Congress. Rails should be as hard as is consistent with safety. Mechanical hardening has been largely done away with, owing to the rapid driving in the manufacture. The Congress did not fix on any definite composition, but concluded that hard rails wear best, and were also the safest. The results of tests on Russian State railways, with others for comparison, were given by Mr. Werchovsky as follows :—

Description of Steel Rails.	Best.	Good.	Brittle.	Soft.	Russian.	German.	English and French.
Carbon per cent. . .	0·28	0·28	0·25	0·21	0·22	0·25	0·36
Manganese ,, . .	0·67	0·60	0·54	0·74	0·53	0·52	0·61
Silicon ,, . .	0·24	0·15	0·11	0·05	0·11	0·16	0·11
Phosphorus ,, . .	0·11	0·11	0·18	0·19	0·18	0·12	0·09
Tensile strength { kilos. per sq. mm.	66	64	60	52	56	61	66
Tensile strength { tons per sq. inch .	42	41	38	33	36	39	42
Elongation per cent. . .	19	19	20	20	19	19	18
Reduction of area per cent. .	36	43	47	53	45	44	40

In the above table the best rails show a high percentage of silicon. Generally, it is considered that this element should be low when the phosphorus and carbon are high, but this hardness gives durability under wear. High tensile strength is not required, as in ships' plates. Further, high silicon tends to make the metal quiet in the moulds, and to remove slag and gas, so that the metal is not likely to peel or laminate. The author has generally preferred to have at least 0·10 per cent. of this element present; but, to test the question, he has performed a number of experiments on high-silicon steel rails. Fully tabulated results are given, and the following conclusions are drawn:—

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* *Proceedings of the Institution of Mechanical Engineers*, 1890, pp. 301–359; 3 plates.

A heavy steel rail, containing silicon up to 0·30 per cent., and the same amount of carbon, will stand any ordinary transverse test under a falling weight up to, say, 1 ton falling 5 feet midway between bearings 3 feet apart, provided the phosphorus is low, say under 0·07 per cent., and the manganese not too high. Thus, the large amount of silicon does not seem to make the rail brittle, judging, at least, from these experiments.

Silicon up to 0·30 per cent. makes no visible difference in the hardness, so far as is shown by deflection under the falling weight, or by impact or by tensile tests—the different results obtained being altogether dependent upon the proportion of carbon.

Silicon at 0·20 per cent. and upwards gives a sound ingot with a clean, solid top, which rolls out into a rail with fewer defects than steel that contains only 0·06 per cent. of silicon, other impurities being the same.

By silicon up to 0·30 per cent., with carbon up to 0·30 or 0·40 per cent., the steel is neither hardened nor made brittle, and its strength is diminished in only such a small degree as not to imperil the safety of the rail, judging, at least, from a severe transverse impact test under a falling weight.

Silicon up to 0·20 or 0·30 per cent. certainly makes the steel quiet in casting, and free from small honeycombs or blisters; but in cooling from a fluid to a solid state it draws or shrinks much more than rail-steel containing only 0·10 per cent. of silicon, or less. The ingots, particularly large ones weighing a ton or more, are very liable in cooling to form a hole in the centre, which, when the ingot is rolled into rails, produces in the web or neck of the rail a seam not welded. From this fault a fracture of the rail may occur, and may be more disastrous than the peeling off in thin scales that arises from small blisters round the exterior surface of the ingot, which are formed when silicon is low. Thus high silicon steel can be used with safety in small ingots only—say of not more than half a ton. This explains the favourable results obtained with such steel in Russia, where probably small ingots are made for single rails only. In the large ingots of, say, 1 ton and upwards, for three or four rails as now rolled in England, more than 0·10 to 0·15 per cent. of silicon should not be aimed at, on account of the greater shrinkage produced by it. The danger is therefore seen of fixing upon one composition as applicable to all makes of steel; and it is clear that care should be taken in considering all the reasons before changing the practice. For instance, what will do for working small ingots in Russia and elsewhere will not answer for large ingots as worked in England; and engineers would do well to leave the silicon question to the railmaker, who in every case has the best experience of what suits his own requirements and those of the users generally. These results respecting shrinkage arising from silicon in steel agree with those given by Mr. Hadfield.

As for a high percentage of silicon in basic steel, it has the same effect on shrinkage as in the Bessemer steel. But it should be remembered that silicon, added in the form of hæmatite pig iron before the manganese is put into the ladle, is what prevents the rephosphorisation of the basic steel; and that without this discovery the basic steel rails would have died a natural death. However, there is only just enough silicon added to take up the oxide of iron and protect the steel from rephosphorisation, and none, or very little, is left in the steel, say from a mere trace up to only 0·06 per cent.; and as there would be the same shrinkage in large ingots as with high-silicon Bessemer steel, no experiments with basic steel have been found necessary.

Thus, both for Bessemer and for basic steel, the presence of such a high percentage of silicon as is used in Russia, say 0·25 per cent., seems not applicable in England, unless small ingots were reverted to; which, again, would be a disadvantage, because the larger ingots mean more work put upon the steel, and, therefore, better rails. The hardness does not, then, appear to depend on the silicon, but on the phosphorus and carbon. The mode of cooling affects the hardness considerably, and it may be found that covered hot banks, to produce uniform cooling, will give good results. Hot cambering, instead of cold straightening, and all the conditions under which the rails are used, have their bearing on this question of hardness. Generally speaking, the author is not inclined to overdo the hardness, and thereby risk safety, as the rails are already so cheap and durable. The use of heavier rails is then referred to, and the question of flange *versus* bull-headed rails is touched upon. It is pointed out that each railway must retain its special form of rail, as the change is next to impossible. On a new line it is feasible to choose the best form. Apparently the best system of permanent way is the English system, with bull-headed rails and chairs; next to this comes a heavy flange rail laid on steel base plates. The question of the various forms of flange rails is then discussed, and it is pointed out that the weak part of the present form is the method of laying them on the sleepers. This point is quite as important as the rail-joints themselves.

In the discussion, Mr. W. Richards pointed out the advantage of longer rails, which diminished the number of joints. A rail should contain from 0·35 to 0·45 per cent. of carbon, up to 1 per cent. of manganese, and phosphorus as low as possible. Mr. J. Head preferred the flange rail, as the foot prevented it from turning over; but Mr. J. Tomlinson pointed out that much more time was required to change a flange rail than a bull-headed rail.

CHEMICAL PROPERTIES.

Action of Tidal Streams on Metals.—An extensive series of experiments has been carried out by Mr. T. Andrews * to determine the action of tidal streams on metals, principally on wrought iron, steel, and cast iron. For the purposes of this research, two turned bars were placed in a cell divided into two by a porous partition. One department was filled with sea-water, the other with distilled water. The electro-motive force of this cell was measured at frequent intervals during six hours, as was also the electro-motive force. The full results for twelve sets of tests are given in tabular form, and are also plotted as curves. Analyses of the metals are appended. In every instance the greatest electro-motive force was observed from the tidal action on hard steels. Soft steels averaged less electro-motive force than rolled wrought iron, but gave a higher force at the commencement of each experiment. Rolled wrought iron gave more than hammered wrought iron, and the latter, together with one sample of cast metal, gave the least electro-motive force. In many instances the electro-motive force reached one-tenth to one-seventh of a volt. The most destructive action is exerted at the lower part of the structure, which lies in the salter water, as it is in an electro-positive condition. In the discussion, it was pointed out that this voltaic action might have some effect on the corrosion of boilers, which are fed with more or less impure water, as there is more salt in the water in the boiler than there is in the feed-water.

Heat Transmission through Cast Iron Plates.—In a paper read before the American Society of Mechanical Engineers on November 14, 1890, Mr. R. C. Carpenter described a series of experiments made to ascertain the relative heat transmission through cast iron plates, in the condition in which they leave the foundry, and through the same plates treated with dilute nitric acid for periods of nine, eighteen, and forty days respectively. The results show a marked change in the conducting power of the plates, due to a prolonged treatment with acid, and appear to indicate that a beneficial effect might be expected by treating the castings of steam-engine cylinders in such a bath. The action of the acid in dissolving the iron and not attacking the carbon tends to form a protecting surface on the iron. The following figures show the relative transmission of heat through plates pickled in a 1 per cent. nitric acid solution and in a 5 per cent. solution, as compared with an untreated plate, taken as 100:—

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* *Proceedings of the Federated Institution of Mining Engineers*, vol. i. pp. 191-208; one plate.

Length of treatment	9 days	18 days	40 days
Plates pickled in 1 per cent. acid	86·3	70·7	68·7
Plates pickled in 5 per cent. acid	76·8	70·0	68·5

Electro-Chemical Effects on Magnetising Iron.—Mr. T. Andrews* has continued his researches† on the current produced when the opposite poles of two electrically connected magnets of approximately equal strength are immersed in solutions of various substances. The general results obtained were, that the north pole became positive to the south pole. In the present investigations the solutions were applied to the upper ends of the magnets, as it was thought that the current produced in previous experiments might have been due to the weakening of the submerged north pole, owing to its relation to the earth. The north pole was still found to be positive, but the electro-motive force was slightly less than before. In both cases it was frequently observed that the south pole became momentarily positive at the commencement of the experiment.

The Passive State of Iron and Steel.—According to Mr. T. Andrews,‡ the passive state of iron appears first to have been observed just a century ago by Keir, and brought before the notice of the Royal Society in 1790. He observed that strong nitric acid had no action on iron when the metal was placed therein. Since then, Bergman, Schönlein, Faraday, Herschel, and others have conducted investigations in relation to this phenomenon. In the present paper are presented the results of a study of certain magnetic, temperature, and other conditions which the author found to affect the passive state of iron and steel. The experiments are classified under the following heads:—

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* *Proceedings of the Royal Society*, vol. xlvi. pp. 176–193.

† *Journal of the Iron and Steel Institute*, 1888, No. I. p. 370.

‡ *Proceedings of the Royal Society*, vol. xlviii. pp. 116–126.

Series I., containing the results of observations on the influence of magnetisation on the passive state of steel in cold nitric acid, specific gravity 1·42.

Series II., treating of the influence of magnetisation on the passive state of steel in warm nitric acid, specific gravity 1·42, the experiments showing that magnetised steel bars were less passive in warm nitric acid than unmagnetised ones.

The chemical composition and physical properties of the steel used are given in detail in the paper, together with the methods employed in the investigation, and detailed illustrations of the various apparatus used in course of the research. The results of the investigation are given in detail. The whole of the results afford an indication that magnetisation of comparatively low intensity, acting during considerable periods of time, exerts only a limited modifying influence on the passivity of iron or steel in the cold, though the influence is discernible when employing a delicate galvanometer. Magnetisation, with the nitric acid at a higher temperature, produces a quicker effect. In a recent research by the author, "On Electro-Chemical Effects on Magnetising Iron, Part II.," it was noticed that local currents were set up between the polar terminals and central portions of steel magnets exposed as electrolytes; and this class of local action, together with a slight alteration of the physical structure of the magnet bars, consequent on their magnetisation, may possibly be involved in producing the effects due to magnetism on passive steel or iron in concentrated nitric acid.

Graphite in Cast Iron.—Berthelot and Petit * have experimented with the different forms of graphite derived from cast iron, electric light carbons, and plumbago. The investigation chiefly deals with the so-called oxides of these graphites, and the authors incline to the view advanced by Brodie, that these graphites are distinct radicles.

Chrome Iron.—When a mixture of ferrous chloride and chromic chloride in suitable proportions is heated to redness in an atmosphere of hydrogen, S. Meunier † finds that a silvery-white, distinctly magnetic metal is obtained. It has the following composition:—

Iron.	Chromium.	Total.
35·01	64·80	99·81

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* *Comptes Rendus de l'Académie des Sciences*, vol. cx. pp. 101–106.

† *Ibid.* pp., 424–426.

It is not attacked by boiling concentrated nitric or hydrochloric acid, and only very slightly by aqua regia. Heated to redness in a current of steam, this alloy is completely oxidised, yielding chromite, with a specific gravity of 4·48, identical in all respects with the natural mineral.

The Gesner Rust-Proof Process.—The iron or steel to be treated by this process is heated to a high temperature in a retort in an atmosphere of steam introduced through a red-hot pipe. Naphtha is then introduced into the retort and the heating continued. The whole operation lasts about 1 hour and 20 minutes. Mechanical tests of iron and steel treated by this process gave the following results:*—

Description.	Elongation.	Reduction of Area.	Elastic Limit.	Ultimate Stress.
	Per Cent.	Per Cent.	Lbs. per Square Inch.	Lbs. per Square Inch.
Iron—				
Untreated	10·5	12·9	32,350	45,040
	10·1	11·6	33,750	44,880
Treated . . .	8·4	13·4	33,740	42,620
	6·6	11·6	33,640	45,770
Steel—				
Untreated	21·6	43·3	41,960	58,250
	19·1	42·8	43,050	59,120
Treated	24·1	40·9	39,050	55,880
	26·0	44·9	37,390	55,220

The Protection of Iron from Rust.—According to the *Ungarische Metallarbeiter*,† a firm, black protecting coat can be given to any iron article in the following manner:—Heat the metal, after coating it lightly with linseed oil, in a clear coke fire. If the black coating so effected is not regular in its character, repeat this operation until the desired colour has been obtained. Then clean the surface with leather and a little linseed oil. A dull black surface may be produced by rubbing with oil the surface of the metal just after it has been taken from the fire.

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* *Iron Age*, vol. xlv. p. 544.

† Through *Stahl und Eisen*, vol. x. p. 822.

CHEMICAL ANALYSIS.

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I.—*ANALYSIS OF IRON AND STEEL.*

The International Iron and Steel Standards.—In the second report of the British Association Committee appointed to consider the best method of establishing an international standard for the analysis of iron and steel, it is stated that in the first report of the committee,* presented at Newcastle-on-Tyne, the objects of the committee were defined, and the methods which it was proposed to adopt were indicated. It was arranged that five samples of steel, in the form of fine turnings or drillings, should be prepared under the superintendence of Professor Langley, and that these samples should contain, as nearly as possible, 1·3, 0·8, 0·4, 0·15, and 0.07 per cent. of carbon respectively. It was further arranged that the samples so prepared should be divided among the respective committees in the United Kingdom, America, France, Germany, and Sweden, and in each country analyses should be performed by not more than seven chemists of repute, and that from the results so obtained the actual composition of the samples should be ultimately deduced.

When the last report was presented four of these samples had been prepared, and had been despatched in air-tight leaden cases to the respective committees in the five countries above mentioned; but at the time the report was presented the cases consigned to the British Association Committee had not arrived. These were very shortly afterwards received in good condition, and were opened by the secretary, and under his direction the samples were hermetically sealed in small glass tubes, each containing about 20 to 30 grammes, as arranged by the committee.

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* *Journal of the Iron and Steel Institute*, 1890, No. I. p. 868.

It was anticipated that the fifth sample would have been prepared shortly after the last report was presented, but this sample has not yet been received, and its production has apparently been delayed by the fact that the American committee has entered upon an investigation of the relative accuracy of different processes of analysis, which, though of great interest and importance, was not included in the suggestions which were originally adopted. The result was, that delay took place before the analysts in the United Kingdom were supplied with their samples, as it was intended to forward the five standards together. The four samples were, however, distributed as arranged after a few months' delay, and in most cases the analyses have been completed, and the results have been returned to the secretary of the committee. The fifth standard will be sealed in glass tubes in the same way as the others immediately it is received, and the analysts will be at once supplied with their sample tubes for examination.

In the meantime the committee cannot discuss the results which have been received, but it is probable that a third and final report will be presented to the Association at its next meeting.

The Determination of Carbon.—The method of determining the free and combined carbon in iron and steel proposed by O. Pettersson and A. Smitt * is, briefly, as follows :—

A weighed quantity (0·2 to 0·8 gramme) of iron, in the form of a thin sheet, is plunged into molten hydrogen potassium sulphate. The iron becomes converted into ferric sulphate, and the combined carbon is oxidised to carbonic anhydride, which, together with the evolved sulphurous anhydride, is absorbed by a known quantity of a solution of sodium and barium hydroxides. The barium sulphite is oxidised to sulphate by the addition of a little potassium permanganate solution; the carbonate is then decomposed by nitric acid, and the carbonic anhydride determined. The fused mixture of potassium hydrogen sulphate and ferric chloride is dissolved in hydrochloric acid, the graphite collected on a platinum funnel, filtered through asbestos, and the whole dried and weighed. A mixture of air and nitrous fumes is now passed through the funnel, which is heated to redness. When all the graphite is burnt the funnel is weighed, and is ready for another determination. The accuracy of this method is from 0·06 to 0·02 per cent.

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* *Berichte der deutschen chemischen Gesellschaft*, vol. xxiii. pp. 1401–1402.

The Determination of Chromium.—R. Namias,* in determining the chromium present in chrome iron alloys containing about 25 per cent. of chromium, fuses 1 gramme of the alloy with from 8 to 10 grammes of potassium bisulphate for about one hour, when another 3 grammes of the bisulphate is added, and the fusion continued for a few minutes, in order to convert the insoluble basic sulphates formed by the prolonged fusion into soluble neutral salts.

The mass is then extracted with water and hydrochloric acid, and the residual silica filtered off, ignited, and weighed. Occasionally this silica is found to contain a little chromic oxide. When this is the case, the silica must be re-fused with bisulphate. In separating the silica it is not necessary to evaporate to dryness, as it is present solely in the insoluble form.

The filtrate is reduced to a definite volume, and a portion of this, equivalent to about 0·25 gramme of the alloy, is neutralised with caustic alkali, heated, and then about 0·5 gramme of magnesia made into milk with water is carefully stirred in. The solution is then heated until the whole of the precipitate has settled and the supernatant liquor is clear. The precipitate is filtered off, washed, and ignited. It is then finely ground in an agate mortar, and fused in a platinum crucible with potassium chlorate and fusion mixture. The fused mass is treated for some hours with hot water, the whole of the chromates passing into solution, and any manganates present being decomposed. After filtering, the chromate is reduced with hydrochloric acid, and the chromic hydrate precipitated with ammonia.

The manganese may be determined colorimetrically, but the chromium must first be eliminated, in consequence of the green colour of its solution. A portion of the solution after filtration from silica, equivalent to 0·1 gramme of the alloy, is treated with barium chloride, to eliminate sulphuric acid, the barium sulphate filtered off, the filtrate nearly neutralised with soda, and barium carbonate stirred in. The solution is then heated till clear, brought to a definite volume, poured through a dry filter, and one-half taken for the determination of the manganese in the ordinary manner.

To determine the iron, evaporate to dryness a portion of the solution equivalent to about 0·1 gramme of the alloy, and treat with sulphuric acid to eliminate the hydrochloric acid, take up, reduce with zinc, and titrate.

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* *Stahl und Eisen*, vol. x. p. 977.

The Determination of Copper in Iron.—C. Holthoff[*] points out that, after the copper has been separated in the form of copper sulphide, this precipitate should, after filtration, be burnt wet in a porcelain crucible. If previously dried, it is almost impossible to decompose the sulphate formed, even by heating during a period of many hours.

The Determination of Phosphorus.—Mr. C. Jones[†] gives some notes on various methods employed for the determination of phosphorus in iron and iron ores. Special reference is made to the use of a solution of ammonic sulphate for washing the phospho-molybdate precipitate, and a large number of tests are given to show that the precipitate is not dissolved by this reagent. Nitric acid or ammonium nitrate can thus be dispensed with, and the titration can then be performed without difficulty. The use of permanganate for oxidation is referred to, and also the "reductor" method of filtering through zinc for reduction. The method adopted is as follows:—Dissolve in nitric acid of 1·135 specific gravity, boil for one minute, add potassium permanganate till the oxide appears, then add a few small crystals of ferrous sulphate. Filter; add sufficient ammonia, and when the solution clears, add a few drops of permanganate to ensure oxidation, again dissolving if necessary. At 85° C. add 75 cubic centimetres of ammonic molybdate, shake for five minutes, filter, wash with ammonic sulphate. Dissolve the precipitate in ammonia of 0·90 specific gravity, without puncturing the paper. Add 30 to 50 centimetres of sulphuric acid to the solution, and put it through the "reductor." Titrate as usual with the ordinary correction for zinc. A determination by this method took fifty minutes; for iron ore a little more time is required.

In order to obtain the whole of the phosphorus in a state precipitable as molybdate without evaporating the nitric acid solution to dryness and igniting the residue, Herr Meinecke and Mr. Wood recommend oxidation with chromic acid. They dissolve 4·375 grammes of the sample in 40 to 50 cubic centimetres of nitric acid of specific gravity 1·3, add 30 centimetres of sulphuric acid diluted with an equal volume of water, evaporate down to 20 centimetres, and then add 2·5 to 3 grammes of chromic acid. Boil for ten minutes to complete the oxidation, cool partly, and dilute. Make the solution up to 250 centimetres, and filter through a dry filter. Take 100 centimetres, partly neutralise with ammonia, heat to 85° C., and add 50 to 100 centimetres of the molybdic reagent. Allow the precipitate to settle, decant and filter, dry and ignite moderately to form molybdenum phospho-molybdate. Each gramme of the precipitate corresponds to 1 per cent. of phosphorus.

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[*] *Zeitschrift für analytische Chemie*, 1889, p. 680.

[†] *Transactions of the American Institute of Mining Engineers*, vol. xix. (Advance proof).

Von Reiss * uses potassium manganate in place of chromic acid with success.

The Determination of Silicon.—M. Clerc † determines silicon in ferro-silicon and in silicon-spiegeleisen by dissolving a weighed quantity of the finely powdered metal in about 20 cubic centimetres of water and 8 to 10 of bromine, followed by the addition of 75 of concentrated hydrochloric acid. The solution is evaporated to about 40 cubic centimetres, the silicon remaining then as an insoluble residue; on filtration no silica can be detected in the filtrate.

The Determination of Sulphur.—C. Reinhardt ‡ observes that, of the various methods known to him by which the sulphur present in iron or steel is determined in the form of barium sulphate, there is not one which takes less than twelve hours to complete, to a great extent owing to the length of time that must be allowed for the complete separation of the barium sulphate. The following modified method enables this determination to be made within a much shorter period. The method is as follows:—Decompose the iron or steel in which the sulphur is to be determined, with hydrochloric acid of the specific gravity 1·19, and collect the sulphuretted hydrogen evolved in a caustic soda solution which contains some sulphuric acid, the percentage of which must be known. The sodium sulphide so formed is converted by hydrochloric acid and bromine water into sodium sulphate, the excess of bromine eliminated by the use of arsenious acid and the sulphuric acid precipitated boiling by barium chloride.

The author describes the apparatus he employs. The quantity of pig iron taken for the analysis is 5 grammes, and for ingot iron or steel

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* *Journal of the Iron and Steel Institute*, 1890, No. I. p. 370.

† *Mémoires de la Société de l'Industrie Minérale*, 1889, p. 107.

‡ *Stahl und Eisen*, vol. x. pp. 430–433.

10 grammes; 60 cubic centimetres of hydrochloric acid being employed for the solution in the former case, and 100 in the latter.

The caustic soda solution used contains about 250 grammes to the litre, and should contain a quantity of sulphuric acid about equivalent to 0·1 gramme of barium sulphate for every 100 cubic centimetres of solution. The addition of sulphuric acid to the soda solution is based on the fact that the greater the quantity of sulphur present in the solution the more rapid will be the precipitation by barium chloride.

M. Lucion states that sulphuric acid may be determined by barium chloride even in the presence of free bromine. L. Blum,* however, says this process is inapplicable to steel. In the case of this metal the barium precipitate will contain carbon compounds derived from the oxidation of the carbon in the original steel. On filtering, these carbon compounds close the pores of the filter paper, and render filtration a slow process, thus doing away with the advantage otherwise gained of not having to evaporate the bromine solution.

The Analysis of Spiegeleisen.—Baron von Jüptner† has drawn attention to the frequent irregularity observed in the composition of different portions of samples of metal submitted to analysis, and he instances a case in which nine determinations were made of the manganese present in a sample of spiegeleisen. These vary from a percentage of 6·30 to one of 13·13, the average being 10·80.

II.—*ANALYSIS OF IRON ORES AND SLAGS.*

Determination of Phosphoric Anhydride.—O. Reitmair ‡ discusses the citrate method for the determination of phosphoric acid, especially as applied to the examination of basic slag. The method is, he shows, subject to a number of inaccuracies, which the author describes at great length.

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* *Zeitschrift für analytische Chemie*, vol. xxix. p. 138.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 273.

‡ *Zeitschrift für angewandte Chemie*, 1889, p. 702; 1890, pp. 19 and 196.

III.—*FUEL ANALYSIS.*

Assay of Coal.—M. Max Evrard [*] describes the method of separating coal from shale and stones by means of a saturated solution of zinc sulphate, in which the former floats, while the latter sinks. The application of this to the assay of coal on a small scale is described.

IV.—*GAS ANALYSIS.*

The Analysis of Blast Furnace Gases.—P. Gredt [†] determines the moisture and dust in the gases issuing from blast furnaces by the aid of an apparatus consisting of a glass tube—the "dust" tube—15 millimetres in diameter, partly filled with wadding, and a calcium chloride tube. The blast furnace gases are drawn direct into the filtering tube, and thence to the calcium chloride tube, the arrangement being similar to that used in making the tests of chimney gases at the National Smoke Abatement Exhibition of 1882. [‡] The gas analysis was performed in the ordinary manner, a Bunte burette being employed.

R. Namias [§] describes a slightly modified form of the Orsat gas apparatus as commonly employed. The modifications adopted have for their aim the better bringing together of the gases and the absorbing solutions, and the rendering the apparatus automatic in its action.

M. Rasine [||] has devised a modified indicator for the determination of the presence of carbonic oxide in gas mixtures not containing hydrocarbons. A platinum sponge is employed to dissolve the carbonic oxide, the solution being accompanied by a rise of temperature. Any increase in temperature due to this cause is made evident by an electric indicator.

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[*] *Bulletin de la Société de l'Industrie Minérale*, 3rd series, vol. iii. p. 317.

[†] *Stahl und Eisen*, vol. x. p. 592; three illustrations.

[‡] See *Report*, with illustration of the apparatus.

[§] *Stahl und Eisen*, vol. x. p. 788, with illustration.

[||] *Revista Minera*, vol. xli. p. 22.

STATISTICS.

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I.—*UNITED KINGDOM.*

The Iron and Steel Imports and Exports for 1890.—The following statement gives the imports of iron ores, iron, and steel into the United Kingdom in 1890, as compared with the previous year:—

Description.	Quantities.		Values.	
	1889.	1890.	1889.	1890.
	Tons.	Tons.	£	£
Iron ore	4,023,620	4,469,390	3,121,357	3,586,456
Bar, angle, bolt, and rod iron	111,803	92,899	1,034,102	925,318
Steel, unwrought . . .	10,870	8,144	96,865	85,442
Girders, beams, and pillars .	82,065	71,833	520,212	512,000
Unenumerated . . .	148,866	150,464	2,490,986	5,682,855
Totals . . .	4,377,224	4,792,730	7,263,522	10,792,071

The exports of coal from the United Kingdom during the first half of 1890 amounted to 14,277,056 tons, and for the second half of the year the exports were 15,852,971 tons, the total exports for the year amounting to 30,130,027 tons. This is an increase of 1,173,582 tons on the exports for the previous year.

The exports of iron and steel from the United Kingdom in 1890 and 1889 were as follows:—

Description.	Quantities.		Values.	
	1889.	1890.	1889.	1890.
	1=1000 tons.	1=1000 tons.	£1 = £1000.	£1 = £1000.
Pig iron	1,190	1,146	2,988	3,502
Bar, angle, bolt, and rod . .	252	222	1,624	1,655
Railroad iron	1,090	1,037	5,330	5,988
Wire and manufactures thereof (excluding telegraph-wire) .	56	61	832	1,083
Hoops, sheets, and plates .	386	337	4,134	3,844
Tin plates and sheets . .	431	419	6,030	6,361
Cast and wrought iron and steel, unenumerated . . .	463	454	5,431	5,974
Old iron, for remanufacture .	147	150	432	504
Steel, unwrought	150	150	1,699	1,904
Manufactures of steel, or of steel and iron combined . .	21	25	640	770
Totals . .	4,186	4,001	29,140	31,580
Machinery and millwork—				
Steam-engines and parts thereof	...	...	3,827	4,436
Other descriptions . . .	...	...	11,447	11,977
Hardware and cutlery . .	...	...	2,989	2,765
Implements and tools . .	...	...	1,253	1,340
Totals . .	...	...	19,516	20,518

British Shipbuilding in 1890.—The total shipbuilding tonnage built in the United Kingdom in 1890 has been returned at 1,276,129 tons, being a decrease of 50,121 tons, as compared with the previous year. The tonnage built in the principal shipbuilding centres in each of the two years is shown in the following statement:—

Localities.	1889.	1890.
	Tonnage.	Tonnage.
The Clyde	334,454	349,936
The Tyne	281,708	235,062
The Wear	217,332	197,476
The Tees	110,426	127,739
West Hartlepool	85,875	99,847
Belfast	79,853	66,362

The total tonnage of vessels built in iron is returned at 36,031 tons, of which 12,413 tons were constructed on the Tees. The remainder, excepting a very small tonnage of timber-built ships, were in steel.

II.—*AUSTRIA-HUNGARY.*

Mineral Statistics of Austria.—The official statistics * relating to the mineral industry of Austria for the year 1889 show that the production during that year was as follows:—

Description.	Metric Tons.	Value.
		£
Iron ore	1,115,153	207,323
Coal	8,592,876	2,220,661
Lignite	13,845,863	1,905,093

The total production of pig iron amounted to 617,012 tons. This production, together with that of iron ore, was distributed as follows among the several divisions of the Empire:—

Provinces.	Iron Ore.	Forge Pig Iron.	Foundry Pig Iron.	Percentage of Pig Iron Production.
	Tons.	Tons.	Tons	
Bohemia . . .	421,074	143,304	17,489	26·06
Lower Austria . .	8,582	48,132	7,537	9·02
Salzburg . . .	6,484	...	2,447	0·40
Moravia . . .	24,268	144,002	22,191	26·93
Silesia	5,138	36,078	4,397	6·54
Styria	542,760	139,944	2,430	23·08
Carinthia . . .	83,902	38,587	784	6·38
Tyrol	5,299	819	799	0·26
Carniola . . .	6,782	4,642	271	0·80
Galicia	10,864	...	3,249	0·53
Totals . .	1,115,153	555,508	61,504	100·00

The production of pig iron in the different divisions of the Empire during 1889, as compared with that of 1888, increased and decreased as follows:—

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. pp. 335, 350.

Provinces.	Increase.	Decrease.	Increase or Decrease.
	Tons.	Tons.	Per cent.
Bohemia	23,500	...	17·12
Lower Austria	6,683	...	13·64
Salzburg	...	39	1·57
Moravia	12,431	...	8·08
Silesia	...	4,010	9·03
Styria	...	6,775	4·54
Carinthia	...	920	2·30
Tyrol	...	1,480	47·78
Carniola	1,012	...	28·50
Galicia	493	...	17·90

There was, thus, a total increased production of nearly 31,000 tons, or 5·27 per cent.

The value of the foundry pig iron produced was £231,720, and of the forge pig iron, £1,733,068.

The output of lignite increased in every division except Lower Austria, Moravia, and Carinthia, which showed decreases, as compared with 1888, of 69·32, 4·15, and 13·93 per cent., respectively. The largest proportional increase was shown by Dalmatia, with 32·64 per cent.; whilst, although the output of Bohemia increased by as much as 913,092 tons, the proportional increase was only 9·10 per cent. Of the total output of lignite, 79·06 fell to Bohemia and 15·33 per cent. to Styria.

The production of graphite amounted to 22,335 tons, and of manganese ore to 3926 tons.

The coal coked amounted to 989,693 tons, the coke produced being 601,951 tons. The percentage yield was thus 60·82.

Mineral Statistics of Hungary.—According to G. Tirscher,* in 1889 there was produced in Hungary 937,452 tons of coal, valued at £446,745; 1,950,226 tons of brown coal, valued at £581,405; 22,797 tons of patent fuel, valued at £17,985; and 2109 tons of manganese ore, valued at £634.

Bohemian Lignite.—The production of lignite was as follows in the under-mentioned districts of Bohemia during the year 1889:—

Districts.	Production.	Workpeople Employed.
	Metric Tons.	
Elbogen-Falkenau	1,443,083	4,140
Teplitz-Brüx-Komotau	9,437,059	16,177

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* *Ungarische Montan-Industrie Zeitung*, October 1, 1890.

This shows an increase of about 900,000 tons over the output of the same districts in the year 1880.*

The Ostrau Coalfield.—This Austrian coalfield contains about 100 workable beds of coal, the total maximum thickness of the beds being over 260 feet. The first colliery working was started in 1782, and the annual output has now reached 1,500,000 tons. There are 572 coke-ovens in the district; these produce annually some 100,000 tons of coke. The length of railways laid underground is about 250 miles.†

Machinery in Hungary.—Hungarian statistics are in a backward condition, and the latest on the subject of machinery which have been available to the British Consul at Budapest are those for 1888. The imports of machinery for that year amounted to £561,725, of which the principal items were :—

Locomotives, &c.	£42,892
Sewing-machines	115,845
Thrashing ,,	44,779
Mowing ,,	4,860
Sowing ,,	11,728
Ploughing ,,	47,969
Pumps, cranes, presses, &c.	50,571
Parts of machinery	212,119

Hungary is making great efforts to supply her own agricultural machinery, and it is stated that, out of £660,000 worth of agricultural machinery required, £479,000 worth was furnished by Hungary herself.

Death-Rate in Austro-Hungarian Mines.—Official statistics show a rate of two fatal casualties per 1000 lives. In the decade ending in 1889, there were 1838 deaths among miners, the number of whom averaged 82,312 per annum. The death-rate rose to a maximum of 0·340 per cent. in 1885, with a total of 291 deaths; and was at a minimum in 1886, when it was only 0·168 per cent.‡

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. p. 325.

† *Stahl und Eisen*, vol. x. p. 574.

‡ *Engineering and Mining Journal*, vol. l. p. 6.

III.—*BELGIUM.*

Belgian Blast Furnaces.—There are 28 blast furnaces in the Charleroi district, Belgium, and of these, 14 were in blast at June 1, 1890. In the Liége district 11 out of 16 were in blast; whilst in Belgian Luxemburg 4—the total existing furnaces—were at work.

Of these 29 active furnaces, 18 produce forge pig iron, the total daily capacity being 1515 tons; 2 make foundry pig iron, their capacity being 135 tons; and 9 are producing pig iron suitable for steel-making, their daily output being 705 tons.*

Iron Trade Statistics.—The production of pig iron in Belgium in 1889 amounted to 847,260 tons.† There were 33 furnaces in blast. The number of workmen employed amounted to 2796, the mean daily wages being 2s. 5d.

The production of wrought iron was 620,054 tons. There were 583 puddling furnaces, 263 reheating furnaces, and 250 other furnaces of various kinds in operation. The number of workmen employed amounted to 16,708, the mean daily wages being 2s. 10d.

The production of steel comprised 231,847 tons of ingots and castings, and 236,186 of rolled products and forgings. There were 4 open-hearth furnaces, 12 Bessemer converters, and 31 reheating furnaces in operation. The number of workmen employed amounted to 2660, the mean daily wages being 2s. 9½d.

The exports from Belgium ‡ during the first half of 1889 were as follows:—

	Tons.
Coal and coke	2,483,191
Pig iron	3,517
Manufactured iron	10,755
Scrap iron	2,947
Wrought iron—bars, angles	118,622
,, rails	3,169
,, plates	26,413
,, wire	2,386
Steel—cast	1,831
,, sheets and wire	11,131
,, rails	35,080
Total iron and steel	215,851

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* *Moniteur des Intérêts Matériels*, June 8, 1890.

† *Rapport Général sur la Situation de l'Industrie Métallurgique en* 1889.

‡ *Bulletin du Comité des Forges de France*, No. 293.

IV.—*CHILI.*

Coal-Mining in Chili.—The extensive mineralogical collection shown by Chili at the Paris Exhibition of 1889 has induced Professor W. Lastarria,* of the University of Santiago, to collect all the available information relating to the mineral resources of Chili, which he has published in a useful volume.

The country is particularly rich in coal deposits. The mineral is met with in the form of lignite. Traces of anthracite are also found, but not in workable quantities. The lignite is of lower Tertiary age, and the deposits extend from lat. 37° S. to the Straits of Magellan. The principal mines are situated on the coast. The beds dip towards the west, so that the mines extend under the sea, notably at Lota and Puchoco.

Mining is prosecuted chiefly at Lota and Coronel, but operations have recently been extended to the Bay of Arauco, Talcahuano, Lebu, and Magellan. The industry is, however, still in its infancy. The coal at present raised suffices for half the consumption of the country, and a portion of the output is exported. The exports during forty-five years have amounted to 2,351,817 tons, commencing in the year 1844 by an exportation of 5156 tons, and reaching in 1888 as much as 128,386 tons. The consumption of the country amounts to 300,000 tons yearly, so that the output may be estimated at some 400,000 tons per annum. The amount of coal imported is estimated at 300,000 tons, the greater portion of which is used for metallurgical purposes.

Iron Ore in Chili.—According to Professor W. Lastarria,† iron ore is abundant in Chili; but, owing to the cost of fuel and to want of capital, none of it is smelted, although the imports of iron and steel in 1888 exceeded 23,000 tons of tools and 3800 tons of rails. Steps have, however, been taken by the Government to inquire into the iron industry.

The iron ore deposits have been but little studied. It is merely known that the ores are rich, containing from 50 to 80 per cent. of iron. Titaniferous iron ore is met with in all the granites and syenites. Thick veins of hæmatite and magnetite occur in the hypersthenites. In fact, iron ore is found in great abundance in the mountains of Alhue,

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* *L'Industrie Minière au Chili*, Paris, 1890.

† *Ibid.*

Naltagua, Caleo, Limache, Putaendo, Ligua, Longotoma, Tamaya, Tambillos, Serena, Higuera, Le Barco, Zapallar, Carrizal, Cerro-Blanco, Ojanco, and Taltal.

Manganese ore is also abundant. During the last five years the exports amounted to 102,311 tons.

The deposits of iron ore of Chili have been studied in great detail by C. Vattier,* who strongly urges the advantages that would accrue from the introduction of the metallurgical industry into Chili.

V.—*CUBA.*

Mining in Cuba.—The number of manganese mines being opened in Cuba increases every day.† The exportation of manganese ore is acquiring considerable proportions. From July 1, 1889, to June 30, 1890, the exportation of manganese ore from Santiago de Cuba amounted to 2240 tons; whilst from July 1 to August 21, 1890, the amount exported was 4120 tons, or about double in fifty-two days of what was exported in one year.

Of the iron mines in active work, the most important is that of Jaragua, which affords employment to 1700 persons. According to statistics published by *El Avisador Comercial* of Cuba, this company has extracted from August 7, 1884, the day operations commenced, until the present time (12th August 1890) as much as 400 cargoes of ore, the details being as follows:—

Year.	Steamers.	Tons of Ore.
1884	13	23,977
1885	34	80,085
1886	47	110,880
1887	38	94,817
1888	82	204,475
1889	106	255,406
1890‡	80	210,945
Totals	400	980,585

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* *L'Avenir de la Métallurgie du Fer au Chili*, Paris, 1890.

† *Revista minera, metalurgica y de ingenieria*, vol. xli. p. 352.

‡ Up to August 12.

Iron Ore in Cuba.—Mr. Crowe, Consul-General at Havana, in a report to the Foreign Office, draws attention to the importance of the mineral deposits of Cuba. Until 1880 it was thought that copper was the only metal existing in the island, but then iron ore was found in large quantities. The group of Jaruaga iron-mines has now for six years been successfully worked with American capital, and recently another large group has been acquired by a Philadelphian company. The fact of a large amount of American capital having been thus invested has attracted the attention of the natives to the latent wealth of the island, and fresh mines are being eagerly sought for and claimed. The analysis of the surface ore from one of these mines gave 28 per cent. of iron and 29 per cent. of manganese. It is situated on the coast, and it is computed that the surface ore, and that known by borings to exist in the deposits, will give 6000 tons monthly for the next fifty years. The cost of breaking the ore and its shipment to the States is calculated at from 30s. to 40s. per ton, which, at current American prices, should leave a profit of 35s. per ton. Ten distinct groups of iron-mines have been discovered and claimed for working, eight of which are for sale, the owners being too poor to work them. Two only have been sold, as stated above, to Americans, one of which gives 67 per cent. of iron. Some are reported to contain neither phosphorus nor sulphur; another is stated to have 500,000 tons of rich iron ore on the surface, without counting what is below it. All mines are exempt during twenty years from export duty and surface tax, and are allowed free import of coals. These exemptions, the facility of obtaining labour, the low rates of freight to the States, and the steady demand for iron ought to facilitate and render profitable the working of these promising properties. In view of the fact that there is abundance of hard wood in the island, and that coal is free from duty, smelting on the spot could be carried on.

VI.—*FRANCE.*

Coal.—The output of the French collieries during the first half of 1890 is stated * to have been as follows:—

	Tons.
Coal and anthracite	12,648,048
Lignite	228,091
Total	12,876,139

This represents an increase of 969,165 tons, as compared with the output during the corresponding period of 1889.

Iron and Steel.—The French production of pig iron for the first half of 1890 was as follows:—

Description.	Forge Pig Iron.	Foundry Pig Iron.
	Tons.	Tons.
Coke pig iron	728,859	223,066
Charcoal pig iron	5,263	198
Mixed brands	499	10,462
Totals	734,621	233,726
Totals in first half 1889	647,902	205,915
Increase	86,719	27,811

The total production of pig iron thus amounted to 968,347 metric tons.

The production of manufactured iron was as follows:—

	Tons.
Puddled rails	51
Merchant iron—puddled	298,638
„ charcoal	4,609
„ obtained by reheating	61,545
Total merchant iron	364,792
Plates—puddled	61,615
„ charcoal	1,071
„ obtained by reheating	4,236
Total plates	66,922
Total production	431,765

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* *Bulletin de la Comité des Forges de France*, No. 301.

Compared with the production during the corresponding period of 1889, there is an increase in 1890 of 44,300 tons.*

The production of steel during the first half of 1890 was as follows:—

	Tons.
Rails—Bessemer	86,704
„ open-hearth	939
Total rails	87,643
Merchant steel—Bessemer	64,441
„ open-hearth	59,503
„ puddled	6,631
„ cement	627
„ crucible	7,460
„ reheating scrap steel	2,582
Total merchant steel	141,244
Plates—Bessemer	16,823
„ open-hearth	32,318
„ miscellaneous	2,313
Total plates	51,454
Total production of steel	280,341

The production during the corresponding period of 1889 was 246,088 tons.

Iron Ore in Algeria.—The production of iron ore in Algeria* in 1887 amounted to 448,000 tons. Of this quantity, 165,000 tons were obtained from the mines and 263,000 tons from the quarries of the Beni-Saf group. The average selling price was 6s. 3d. per ton for ore from the mines, and 7s. per ton for ore from the quarries. In the departments of Constantine and Oran, the production was 160,000 tons and 278,000 tons respectively. The number of workmen employed amounted to 1279, of whom 306 worked underground.

In 1887 the exports of iron ore from Algeria amounted to 366,000 tons, the destinations being:—

	Tons.
United States	221,000
England	64,000
France	48,000
Germany	18,000
Belgium	13,000
Italy	2,000

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* *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 270.

VII.—*GERMANY.*

Production of Pig Iron.—The production of pig iron in Germany, including Luxemburg, was as follows during the first six months of 1890:*—

	Metric Tons.
Forge pig iron and spiegeleisen	1,086,825
Foundry pig iron	264,920
Acid Bessemer pig iron	232,037
Basic pig iron	755,601
Total	2,339,383 †

The production during the same period of 1889 amounted to 2,092,376 tons.

At June 30, 1890, 66 works were producing forge pig iron and spiegeleisen, 28 foundry pig iron, 10 acid Bessemer pig iron, and 26 basic pig iron. This shows an increase, as compared with June 30, 1889, of one works making acid Bessemer iron, and four works making basic iron; whilst there is a decrease of two in the number of works making foundry iron.

Imports and Exports.—The imports and exports of iron ore, iron, and steel into and from Germany during the first half of 1890 were as follows: ‡—

Description.	Imports.		Exports.	
	First Half 1889.	First Half 1890.	First Half 1889.	First Half 1890.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
Iron ore	779,575	605,278	1,125,181	1,086,605
Pig iron	213,973	101,199	62,817	88,585
Scrap	14,920	5,132	14,994	18,044
Blooms, ingots, &c.	1,046	346	6,901	10,789
Angle iron	537	114	23,198	27,867
Sleepers, chairs, &c.	132	46	15,610	11,545
Rails	669	549	56,168	50,525
Bar iron	15,453	8,263	53,955	90,573
Manufactures inclusive of above	41,055	24,576	331,611	403,836
Machinery	25,271	18,443	38,030	34,742

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* Compiled from the monthly reports appearing in *Stahl und Eisen.*

† This total is given as 2,339,583 in *Ibid.*, vol. x. p. 739.

‡ *Ibid.*, p. 814.

Mineral Statistics of Bavaria.—According to the official statistics * of Bavaria, the production of coal in 1889 amounted to 771,766 tons, valued at £372,372; that of brown coal amounted to 5616 tons, valued at £1264. There were 20 collieries in operation, employing 4042 workmen; and 6 brown-coal mines, employing 48 workmen. The production of iron ore was 130,934 tons, valued at £27,470. There were 34 iron-mines, and 642 workmen were employed. There was but 1 manganese mine. This afforded employment to 3 workmen, and produced 170 tons of ore, valued at £94. The production of graphite amounted to 3326 tons, and that of refractory clay to 91,465 tons.

The production of the Bavarian ironworks and foundries during the year 1889 was as follows. :—

Description.	Tons.	Number of Works.	Number of Workmen.
(*a.*) Pig iron	59,345	3	380
(*b.*) Castings from ores . . .	115	(*a*)	(*a*)
(*c.*) Castings from pig iron . .	51,575	66	3501
(*d.*) Bar iron	82,760	19	2363
(*e.*) Sheet iron.	3,740	(*d*)	(*d*)
(*f.*) Iron wire	7,509	(*d*)	(*d*)
(*g.*) Steel	18,809	3	247
Totals . . .	223,853	91	6491

Iron Trade Statistics of Lorraine.—Recently published official statistics show that there were in Lorraine, in 1889, 26 iron ore mines, and 10 open workings, 2 coal-mines, 6 ironworks with 21 blast furnaces, 13 ironfoundries, 9 works making weld iron, and 3 making ingot metal. These gave employment to 15,196 operatives.

The production and value was as follows : †—

Description.	Metric Tons.		Value.	
	1889.	1888.	1889.	1888.
			£	£
Iron ore	2,959,255	2,805,264	327,517	299,915
Coal	720,607	689,135	292,168	256,897
Pig iron	563,478	543,098	1,088,464	999,963
Weld iron	152,827	155,798	905,585	822,325
Ingot iron	111,128	106,890	601,790	536,912

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* *Berg- und Hüttenmännische Zeitung*, vol. xlix. p. 391.

† *Glückauf*, 1890, p. 316.

Iron Trade Statistics of Upper Silesia.—The production of iron ore in Upper Silesia during the year 1889 amounted to 795,635 metric tons, of which 7102 tons were clay ironstone, and the remainder brown iron ore. The production in 1888 amounted to 641,096 tons. The value of the iron ore raised in 1889 was £190,218. Of the 58 existing iron ore mines, 9 were altogether and 7 partially idle during 1889.

The 14 works producing blast furnace coke possessed 153 batteries, containing 2340 ovens of various types. At 4 works Appolt ovens were in use; at 4, Coppée ovens; at 2, Otto-Hoffmann ovens; and at 4 other, Wintzek ovens. Other types were also in use. The production of lump coke amounted to 829,056 tons, and of small coke 79,686 tons, as compared, respectively, with 775,642 tons and 72,800 tons in 1888.

The production of pig iron in 1889 was as follows: *—

Description.	Metric Tons.	Per Cent. of Total Production.
Forge pig iron	338,316	70·43
Foundry pig iron	26,610	5·54
Acid Bessemer pig iron . .	24,104	5·02
Basic pig iron	90,858	18·92
Spiegeleisen	470	0·09
Totals	480,358	100·00

This production is 9·55 per cent. in excess of that of 1888.

The materials charged into the blast furnaces in 1889 amounted to:—

	Metric Tons.
Upper Silesian brown iron ore	717,943
Clay ironstone	10,646
Red hæmatite	397
Spathic iron ore	67,407
Pyrites residues	68,048
Magnetite	69,750
Bog iron ore	3,759
Blackband	165
Chrome iron ore	54
Scrap	1,951
Mill scale and cinder	330,092
Limestone and dolomite	378,645
Coke	739,200
Coal	17,034

In addition to this, 66,807 tons of fuel was used in heating the blast, and for the boilers, lighting, and other purposes.

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* *Stahl und Eisen*, vol. x. pp. 564–566 and 648–650.

The fuel required for the manufacture of the ton of pig iron is continuously becoming smaller. Thus, in 1884 it amounted to 1·817 ton, whilst in 1889 it had diminished to 1·574 ton. This reduction has been effected partly by the introduction of brick stoves, but to a great extent, also, owing to the largely increased percentage of cinder added. This amounted in 1889 to no less than 26·1 per cent. of the charge smelted.

The number of blast furnaces was but 38 in 1889, as compared with 44 in 1888. Of these, 29 were in blast for 1462 weeks; the average weekly production of each furnace being 328·7 tons.

The total quantity of charcoal pig iron produced was 1627 tons. The average charge consisted of:—Ore, 3·29 tons; limestone, 0·4 ton; and charcoal, 1·44 ton.

The foundries numbered 24 in 1889. They possessed 52 cupolas and 16 reverberatory furnaces. The production amounted to 34,559 tons of castings, of which 7497 tons was pipe and 766 tons steel castings, 457 tons of which was cast from two open-hearth furnaces. There were used for this production of castings:—

	Metric Tons.
Pig iron	25,807
Scrap	10,472
Steel, wrought iron, &c.	1,211
Ferro-silicon	20
Total	37,510

The loss of metal amounted to 8·53 per cent. The fuel used for melting purposes consisted of 6972 tons of coke and 2281 tons of coal.

The rolling mills numbered, in 1889, 14 works in active operation. They possessed 320 puddling furnaces, 125 welding furnaces, 51 heating furnaces, 1 refining hearth, and 35 furnaces of other kinds. 79 trains of rolls were also in use. The production amounted to 361,564 tons.

The works producing ingot metal numbered 4. These possessed 7 cupolas, 1 acid and 5 basic Bessemer converters, 2 acid and 10 basic open-hearths, 6 welding furnaces, 5 heating furnaces, and 35 other furnaces not specially described. The following quantities of ingots were produced in 1889:—

	Metric Tons.
Acid Bessemer process	15,978
Basic Bessemer process	76,204
Acid open-hearth process	1,678
Basic open-hearth process	35,049
Total	128,909 *

The workpeople employed at the rolling mills numbered 11,796.

The wire mills produced 6275 tons of iron wire and 545 tons of

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* 148,280 in original.

steel wire, 16,700 tons of tacks, 1020 tons of nails, 980 tons of chain, and 2340 tons of springs.

The Ilsede Blast Furnaces.—Blast furnaces II. and III. of the Ilsede Ironworks were in blast during 1889 for 730 days, and during that period produced 115,596 metric tons of pig iron, or an average of 158·35 tons per day, as compared with 158·60 tons in 1888. The materials used included:—Ore and cinder, 324,867 tons; coke, 102,330 tons; charcoal, 291¾ tons. For each ton of pig iron produced, 0·885 ton of coke was consumed.*

The German Iron Trade.—Dr. Rentzsch,† in an address delivered before the Association of German Iron and Steel Workers, drew attention to the progress made by the iron trade of Germany in the years 1879–1888. This progress will be seen from the following table:—

Years.	Forge Pig Iron.	Acid and Basic Bessemer Pig Iron.	Foundry Pig Iron.	Scrap.	Total.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
1888	1,898,125	1,794,806	628,293	15,897	4,337,121
1883	2,002,195	1,072,357	379,643	15,524	3,469,719
1879	1,592,814	461,253	161,696	10,824	2,226,587

The workpeople engaged at the German iron ore mines and ironworks in 1878 numbered 135,973; in 1888 they numbered 206,416.

The Basic Open-Hearth Process.—In a paper read before the Institute of German Engineers, statistics were given by Kintzle, showing the rapid progress that has been made in Germany by the basic process. They are as follows:—

Years.	Production, Metric Tons.			
	Puddled Iron.	Total Steel.	Basic Steel.	Acid Steel.
1883	1,517,410	1,060,592	...	...
1884	1,592,961	1,138,499	260,000	860,000
1885	1,504,072	1,202,090	406,000	742,000
1886	1,414,611	1,376,356	700,000	676,000
1887	1,624,978	1,738,404	900,000	838,000
1888	1,644,442	1,862,676	1,020,000	842,000
1889	1,650,427	2,046,000	1,200,000	846,000

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* *Zeitschrift für angewandte Chemie*, 1890, p. 242.

† *Stahl und Eisen*, vol. x. p. 436.

There are now in Germany fourteen works with fifty converters making basic steel, only three of which partially employ the acid method. Only three steelworks, with eight or ten converters, use the acid process exclusively.

The Iron Industry of Luxemburg.—According to recently published official statistics, nineteen out of the twenty existing blast furnaces were in blast in 1888, and they produced:*—

	Metric Tons.
Forge pig iron	199,151
Foundry pig iron	75,129
Basic pig iron	249,496
Total	523,776

The value of the metal was £923,854. Seven foundries were at work, producing 4615 tons. Only one rolling-mill was in existence, that at Düdelingen, and this made 69,740 tons of products.

The production of iron ore, which was but 725,000 tons in 1868, reached about 3,250,000 tons in 1888. The production of pig iron has increased nearly six times during the same period. The following statement shows the alteration in the manufacture of pig iron since 1880:—

Year.	Forge Pig Iron.	Foundry Pig Iron.	Basic Pig Iron.
	Tons.	Tons.	Tons.
1880	243,000	16,000	...
1884	198,000	76,000	92,000
1888	199,151	75,129	249,496

VIII.—*INDIA.*

Production of Coal.—An official statement has just been published showing the output of coal in the different provinces of India last year, and also the progress made in the coal-mining industry in that country during the last decade. In 1889 the production of coal in all India was 2,045,359 tons, and of this, Bengal contributed 1,641,354 tons, and Assam 116,676; the Central Provinces 144,465, and the

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* *Stahl und Eisen*, vol. x. p. 743.

Nizam's Territory 59,646 tons. Thus, Bengal supplies four-fifths of the total output, the increase in production since 1880 amounting to 100 per cent.

IX.—*ITALY.*

The Iron Trade Statistics.—The output of iron ore in Italy in 1888 amounted to 177,157 metric tons, a decrease of 53,418 tons as compared with the output in 1887.* This diminution is mainly due to a decrease in the output of the Elba mines, which in 1888 amounted to but 154,830 tons, as compared with 208,090 in 1887. The exports of iron ore from Elba amounted, however, to 195,825 tons in 1888, as compared with 175,262 in the previous year. The greater part of this, 115,557 tons, was exported to North America; of the remainder, 61,240 tons came to the United Kingdom. Of the 21,327 tons raised in Lombardy—a slight increase on the previous year—two-thirds came from the mines of Val Trompia. In this district considerable exploratory work has been undertaken by the Terni Steelworks. Only a thousand tons of ore was raised in Piedmont. In 1888 there were 8 blast furnaces in blast, the out-turn of which amounted to 12,400 tons, as compared with 12 furnaces producing 12,265 tons in 1887. The workpeople employed numbered 195.

The production of iron and steel, including manufactures, amounted to 294,554 tons, as compared with 246,096 in 1887. The works numbered 209, giving employment to 12,749 operatives.

The output of coal and lignite, anthracite, and bituminous schist amounted to 366,794 tons, as compared with 327,665 in 1887. The output of peat amounted to 29,925 tons, less than half that of the preceding year.

The compressed fuel or briquettes made during the year, mainly from foreign coal, amounted to 502,249 tons, as compared with 421,014 tons in 1887.

The chief lignite-mine is that of Castelnuovo, in the valley of the Arno, which produced 152,123 tons.

The Manufacture of Steel in Italy.—In 1883 the whole of the steel made in Italy was produced by the aid of the crucible, cement, and other of the older processes, the production being very small.

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* *L'Industria, Rivista tecnica ed economica*, vol. iv. pp. 535–539.

To-day * the production reaches some 160,000 tons, 65,000 of which is made by the Bessemer process, and nearly the whole of the remainder by the open-hearth process. The whole of this Bessemer steel and some 60,000 tons of the open-hearth metal were used in the manufacture of rails. All kinds of material were manufactured out of the steel made, including even armour-plates. Mention should also be made of the Terni, Tardy, and Benech and Raggio Steelworks, as showing the recent progress of the steel industry of Italy.

X.—*RUSSIA.*

Coal.—In returns recently published,† the production of coal at twenty-nine collieries situated in the Donetz basin, during 1889, is given as 967,095 tons, an increase of 141,830 tons compared with the previous year. The increase in the production is mainly due to the increased demand at the new ironworks at Alexandrovsk and Dnieprovsk, and by greater activity in native manufacturing works. The importation of English coal into South Russia during the year 1890 fell off by 50 per cent., and it is being gradually replaced by native coal. The late increase of 40 per cent. in the import duty on foreign coal will probably still further reduce the imports; and in this connection, the Russian Government has asked for information from the colliery proprietors of South Russia as to the condition of their mines, their productive capacity, the extent of the demand for their coal, and whether the output can be increased.

Imports and Exports.—The Russian Customs Department have published a report on the trade of the European frontier and the Caucasian coast of the Black Sea. The customs receipts show an increase over the previous year of £50,000 on cast iron, £83,600 on iron machinery, and £62,000 on coal and coke. Although the imports have increased, the total exports show a decrease of 5·6 per cent. in value.

The imports of coal and coke reached 126,730,000 poods in 1889.‡

Petroleum Exports.—The export of petroleum from Batoum,§

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* *L'Industria*, vol. iv. p. 515.

† *Industries*, vol. ix. p. 484.

‡ *Iron and Steel Trades Journal*, vol. xlvii. p. 269.

§ *The Journal of the Society of Chemical Industry*, vol. ix. p. 776.

the port for Baku, has grown to 649,085 tons in 1889 from 450,326 tons in 1888, or in value to £3,023,300 from £1,724,446. The imports are chiefly those required for the petroleum trade, and consisted of tin plates and some 4000 tons of caustic soda.*

XI.—*SWEDEN.*

Mineral Statistics.—According to the official statistics,† the 393 iron ore mines existing in Sweden in 1889 produced 983,609 tons of ore, added to which 2295 tons of lake ore were also won. The workpeople employed at the mines numbered 6238.

The coal raised in 1889 amounted to 8,238,956 cubic feet, and the fireclay to 2,650,056 cubic feet.

During the year 150 blast furnaces were in operation for an aggregate period of 35,859 days 10 hours. The production of pig iron amounted to 420,664 tons, of which 4622 tons consisted of castings direct from the blast furnace. In the various districts the production was as follows:—

Districts.	Number of Blast Furnaces.	Pig Iron.
		Tons.
Vesterbotten	1	667
Vestermorrland	3	10,998
Gefleborg	18	58,155
Upsala	6	21,190
Stockholm	2	5,813
Kopparberg	32	107,890
Vestmanland	12	35,432
Örebro	43	105,377
Vermland	21	51,883
Södermanland	3	2,988
Östergötland	5	15,687
Kalmar	3	4,264
Jönköping	1	321
Totals	150	420,665

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* Official statistics published by the Russian Ministry of Finance state that the exports of refined petroleum from the Baku district for 1889 were 9,413,281 poods, and 7,917,260 poods in 1888. This shows an increase of 1,496,013 poods, or about 20 per cent. During the same time 17,431,476 poods of petroleum of all kinds, and 2,018,653 poods refined and 14,041,242 poods residual products were despatched to European Russian markets. —*Levant Herald*, June 20, through *The Journal of the Society of Chemical Industry*, vol. ix. p. 777.

† *Bidrag till Sveriges officiela statistik. Kommerse kollegii underdaniga berättelse.* Stockholm, 1890.

As in previous years, the greatest production of any one works was that of the Domnarfet Works, with four blast furnaces, which produced 26,762 tons; the average daily out-turn being 24 tons.

The 122 foundries working in 1889 made 33,005 tons of castings. The total production of castings of all kinds was as follows:—

	Tons.
Castings direct from the blast furnace	4,622
Castings from pig iron	33,005
Castings from open-hearth steel	914
Total	38,541

The production of blooms amounted to 226,071 tons, the producing works being 104 in number. Bar iron, amounting to 274,734 tons, was made at 181 works, possessing 473 hearths or furnaces. Of the bar iron, 192,193 tons represent the quantity of weld iron bars. Of this, 6089 tons were produced in twenty-nine Walloon hearths, 8904 tons in 85 Franche-Comté hearths, 6577 tons in three puddling furnaces, and 176,542 tons in 356 Lancashire hearths.

The number of works possessing Bessemer converters has remained stationary at 15. The production of Bessemer ingots amounted to 80,324 tons. There were 19 open-hearth steelworks, the production having been 55,487 tons. Of other kinds of steel, the production amounted to 2010 tons.

The production of iron and steel manufactures amounted to 74,066 tons, the active works numbering 152. The sheets produced amounted to 27,389 tons, and the nails to 12,072 tons.

The Swedish ironworks in 1889 afforded employment to 23,051 workmen. At the blast furnaces there were 12 steam-engines, with an aggregate horse-power of 462, and at the iron and steel works there were 95 steam-engines with an aggregate horse-power of 4182; the total number of steam-engines in all the mines and smelting-works in Sweden amounting to 225, with an aggregate horse-power of 7465.

XII.—*UNITED STATES.*

The Production of Pig Iron.—Dr. W. M. Sweet * publishes the following tables relating to the production of pig iron in the United States. The output within the last twenty years has almost exactly quadrupled in the Central States of the Union, which made 5,216,591 tons of pig iron in the year ending June 30, 1890, as compared with the total output of 9,579,776 tons. The output of the New England States has remained unchanged in this period, but that of the Southern States has increased from 184,540 tons to 1,780,909 tons, and that of the Western States from 522,161 tons to 2,522,351 tons.

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* *U.S. Census Bulletin*, No. 9.

The following table shows the output in the census year:—

Rank.	States.	Year ended June 30, 1890.		
		Completed Furnace Stacks.	Production of Pig Iron in Tons of 2000 Lbs.	Pecentage of Total Production.
1	Pennsylvania	224	4,712,511	49·19
2	Ohio	71	1,302,299	13·59
3	Alabama	48	890,432	9·29
4	Illinois	15	674,506	7·04
5	New York	37	359,040	3·75
6	Virginia	31	302,448	3·16
7	Tennessee	19	290,747	3·04
8	Michigan	26	224,908	2·35
9	Wisconsin	10	210,037	2·19
10	New Jersey	18	145,040	1·51
11	West Virginia	8	108,864	1·14
12	Missouri	5	99,131	1·04
13	Maryland	14	96,246	1·00
14	Kentucky	6	44,199	...
15	Georgia	5	35,747	1·71
16	Connecticut	8	21,700	
17	Colorado	2	12,949	
18	Indiana	2	11,470	
19	Texas	4	8,950	
20	Oregon	1	8,411	
21	Massachusetts	4	8,381	
22	Washington	1	4,787	
23	Maine	1	3,700	
24	North Carolina	1	3,377	
25	Minnesota	1	...	...
	Totals	562	9,579,880	100·00

During the census year ended May 31, 1880, the production of pig iron amounted to 3,781,021 tons.

At the close of the United States census year 1890 the total number of active blast furnaces was 562, the details being as follows:—

Year.	Anthracite Furnaces.	Bituminous and Coke Furnaces.	Charcoal Furnaces.	Totals.
1890	169	253	140	562
1880	229	195	257	681

The furnaces now erected are as a rule, however, of much larger capacity than was the case in 1880. The following table shows the changes in the fuel used during this interval:—

Fuel Used.	Year ended May 31, 1880.	Year ended June 30, 1890.	Percentage of Increase in 1890.	Percentage of Decrease in 1890.
	Tons.	Tons.		
Anthracite alone	1,112,735	323,258	...	70·95
Mixed anthracite coal and coke	713,932	1,879,098	163·20	...
Coke and bituminous coal	1,515,107	6,711,974	343 00	...
Charcoal	435,018	655,520	50·69	...
Castings direct from furnace	4,229	9,929	134·78	...
Totals	3,781,021	9,579,779	153·36	...

The following table shows the rapid progress of some of the Southern States :—

States.	Year ended May 31, 1880.	Year ended June 30, 1890.	Percentage of Increase in 1890.	Percentage of Decrease in 1890.
	Tons.	Tons.		
Alabama	62,336	890,432	1,328·44	...
Georgia	23,099	35,747	54·76	...
Kentucky	58,108	44,199	...	23·94
Maryland	59,664	96,246	61·31	...
North Carolina	...	3,377	...	...
Tennessee	47,873	290,747	507·33	...
Texas	1,400	8,950	539·29	...
Virginia	17,906	302,447	1,589·08	...
West Virginia	80,050	108,764	35·87	...
Totals	350,436	1,780,909	408·20	...

The Production of Steel.—Dr. W. M. Sweet* states that during the year ending June 30, 1890, the production of steel in the form of ingots or direct castings amounted to 4,466,926 tons of 2000 lbs., as compared with 1,145,711 tons in the year ending May 31, 1880. This comparison will be better seen from the following table :—

Kinds of Steel (Ingots or Direct Castings).	Tons of 2000 lbs.	
	Year ended May 31, 1880.	Year ended June 30, 1890.
Bessemer steel	985,208	3,788,572
Open-hearth steel	84,302	504,351
Crucible steel	76,201	85,536
Clapp-Griffiths steel	...	83,963
Robert-Bessemer steel	...	5,504
Totals	1,145,711	4,467,926

In 1880 steel plants existed in fourteen States. In 1890 the production was as follows :—

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* Preliminary Census Report.

Rank.	States.	Year ended June 30, 1890.		
		Number of Steel-works (a)	Production of Steel of all Kinds. Tons of 2000 Lbs.	Percentage of Total Production.
1	Pennsylvania	79	2,768,253	61·97
2	Illinois	14	868,250	19·44
3	Ohio	18	446,808	10·00
4	West Virginia	2	183,225	4·10
5	New York	8	113,499	2·54
6	Massachusetts	6	30,252	1·95
7	New Jersey	8	17,999	
8	Colorado	1	17,952	
9	California	1	6,904	
10	Michigan	2	5,600	
11	New Hampshire	1	3,700	
12	Connecticut	3	1,734	
13	Indiana	6	1,350	
14	Maryland	1	1,000	
15	Alabama	1	300	
16	Tennessee	4	100	
17	Virginia	1	...	...
18	Kentucky	1	...	...
19	Missouri	1	...	...
	Totals	158	4,466,926	100·00

(a) Each Bessemer, open-hearth, and crucible steel plant is counted as a separate works, although two or more of these plants are frequently embraced in a single establishment.

Of the Bessemer steel ingots or direct castings made in the year under notice, 2,297,726 tons were made in Pennsylvania, 867,805 in Illinois, and 385,576 in Ohio. The Bessemer steel rails made during the same period amounted to 2,036,654 tons. At the end of the year there were fifty-three existing Bessemer steel plants, but of these only fourteen had made rails during the year.

The production of open-hearth steel was 504,351 tons, and of crucible steel 85,536 tons; of these totals, Pennsylvania made, respectively, 406,292 and 64,235 tons. The works containing open-hearth plants numbered fifty-eight, and were situated in twelve States; forty-seven works in eleven States possessed crucible steel plants.

The total production of basic steel during the year amounted to 62,173 tons, nearly all of which was open-hearth metal. The first basic steel produced in the United States was made on May 24, 1884, by the Pennsylvania Steel Company in a Bessemer converter, the first basic open-hearth plant being erected at the Homestead Steelworks of Messrs. Carnegie, Phipps, & Company, Pittsburgh. This plant made its first steel on March 28, 1888, since which date basic steel has been continuously made with such success that, during 1890, the erection of eight open-hearths was commenced as an addition to the existing furnaces; four of these are already in work.

Condition of the Blast Furnaces.—The following tables show the condition of the United States blast furnaces at July 1, 1890. The production of pig iron during the first half of 1890 amounted to about 4,610,000 tons. At July 1, 1890, the furnaces in blast numbered 336, with a weekly capacity of 175,727 tons; at July 1, 1889, the totals were, respectively, 286 and 137,119.

Charcoal Furnaces.

Situation of Furnaces.	Total Number of Furnaces.	Number in Blast.	Capacity per Week.	Number Out of Blast.	Capacity per Week.
			Tons.		Tons.
New England . .	14	6	520	8	570
New York . . .	8	2	284	6	633
Pennsylvania . .	16	4	380	12	690
Maryland . . .	6	2	204	4	410
Virginia . . .	18	3	134	15	740
Ohio	11	7	386	4	170
Kentucky . . .	2	1	112	1	100
Tennessee . . .	6	4	1,030	2	130
Georgia	3	2	338	1	80
Alabama . . .	14	9	2,080	5	1,387
Michigan . . .	24	14	4,632	10	2,310
Missouri . . .	2	2	612	0	0
Wisconsin . . .	6	3	1,369	3	710
Texas	1	1	170	0	0
California . . .	1	0	0	1	120
Washington Territory .	1	0	0	1	170
Oregon	1	1	260	0	0
Totals . .	**134**	**61**	**12,511**	**73**	**8,220**

At July 1, 1889, the charcoal furnaces in blast numbered sixty; their capacity amounted to 10,727 tons per week.

Anthracite Furnaces.

Situation of Furnaces.	Total Number of Furnaces.	Number in Blast.	Capacity per Week.	Number Out of Blast.	Capacity per Week.
			Tons.		Tons.
New York . . .	23	9	3,269	14	3,625
New Jersey . . .	14	6	2,656	8	2,855
Spiegeleisen . .	3	3	206	0	0
Pennsylvania:					
Lehigh Valley . .	45	36	13,515	10	3,172
Spiegeleisen . .	1	1	55	0	0
Schuylkill Valley .	37	21	8,491	16	4,845
U. Susquehanna Valley	18	12	3,732	6	2,120
Lebanon Valley . .	16	12	5,149	4	2,007
L. Susquehanna Valley	16	10	4,920	6	1,465
Spiegeleisen . .	2	2	650	0	0
Totals . .	**175**	**112**	**42,643**	**64**	**20,089**

This shows a very considerable increase in the number of furnaces as compared with the same date in 1889, when the furnaces in blast amounted to but 89, with a weekly capacity of 34,142 tons. In May 1890, however, 123 furnaces, with a capacity of 46,912 tons, were in blast, so that there has since been a considerable falling off.

Coke Furnaces.

Situation of Furnaces.	Total Number of Furnaces.	Number in Blast.	Capacity per Week.	Number out of Blast.	Capacity per Week.
			Tons.		Tons.
New York . . .	4	3	2,954	1	559
Pennsylvania :					
Pittsburgh district .	21	19	23,112	2	1,988
Spiegeleisen . .	1	1	833	0	0
Shenango Valley . .	19	17	12,588	2	1,400
Juniata and Conemaugh Valley . . .	17	11	6,055	6	3,685
Spiegeleisen . .	1	0	0	1	500
Youghiogheny Valley .	5	3	.1,501	2	895
Miscellaneous . .	4	2	1,166	2	1,180
Maryland	5	2	3,640	3	3,830
West Virginia . . .	6	3	2,673	3	770
Ohio :					
Mahoning Valley . .	14	12	10,133	2	1,400
Central and Northern .	18	14	10,367	4	3,340
Hocking Valley . .	15	4	1,444	11	2,300
Hanging Rock . .	14	7	1,488	7	1,242
Indiana	2	1	250	1	130
Illinois	14	12	13,083	2	2,120
Wisconsin	4	3	2,467	1	870
Missouri	6	2	1,552	4	2,150
Colorado	2	1	450	1	430
The South :					
Virginia	13	11	5,939	2	930
Kentucky	4	3	868	1	310
Alabama	36	23	14,029	13	8,233
Tennessee . . .	11	6	3,146	5	2,170
Georgia. . . .	2	2	819	0	0
North Carolina . .	1	1	125	0	0
Totals . .	239	163	120,682	76	39,932

Whilst in this case, too, there has been a considerable increase since 1889, when, at July 1, 136 furnaces, with a capacity of 96,584 tons, were in blast, yet a number of furnaces had been recently blown out, and the production considerably diminished.*

Production of Bessemer Steel Rails.—The American Iron and Steel Association has published statistics showing the production of Bessemer steel rails in the United States during the first half of 1890. This production was as follows:—

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* *Iron Age*, vol. xlvi. p. 141.

States.	First Half of 1890.	First Half of 1889.	Second Half of 1889.
	Tons of 2000 lbs.	Tons of 2000 lbs.	Tons of 2000 lbs.
Pennsylvania . . .	738,931	523,882	578,569
Illinois	279,407	179,201	342,853
Other States . . .	25,916	16,572	5,705
Totals . .	1,044,254	719,655	927,127

Iron and Steel Rails.—The following table shows the mileage of iron and steel rails laid in the United States: *—

Years.	Miles Steel Rails.	Miles Iron Rails.	Total Miles.	Per Cent. Steel of Total.
1880	33,680	81,967	115,647	29·1
1881	49,063	81,473	130,536	37·5
1882	66,691	74,269	140,960	47·3
1883	78,491	70,692	149,183	52·7
1884	90,243	66,254	156,497	57·6
1885	98,102	62,495	160,597	61·0
1886	105,724	62,324	168,048	62·9
1887	125,459	59,588	185,047	67·7
1888	138,516	52,981	191,497	72·3
1889	151,723	51,064	202,787	74·8

The Iron Trade of the United States.—The rapid progress that has been made in recent years by the iron trade of the United States will be seen from the following table, showing the annual production for the years 1886 and 1889:—

Description.	Tons of 2000 Lbs.	
	1886.	1889.
Pig iron, including spiegeleisen	6,365,328	8,516,079
Spiegeleisen	47,982	85,823
Bessemer steel ingots	2,541,493	3,281,829
Bessemer steel rails	1,763,667	1,691,264
Open-hearth steel ingots	245,250	419,488
Open-hearth steel rails	5,255	3,346
Crucible steel ingots	80,609	84,969
Rolled iron, except rails	2,259,943	2,576,127
Rolled steel, except rails	800,000	1,584,364
Iron rails	23,679	10,258
Pig, scrap, and ore blooms	41,909	36,260
Kegs of iron cut nails, 100 lbs.	5,191,984	1,778,082
Kegs of steel cut nails, 100 lbs.	2,968,989	4,032,676
Kegs of steel wire nails, 100 lbs. . .	600,000	2,200,000
Iron and steel wire rods	...	407,513

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* *Poor's Manual*, through *Iron Age*, vol. xlvi. p. 181.

The following table shows the rapid growth of the blast furnace production of the Southern States of the Union during the same period: *—

States.	Pig Iron, Tons of 2000 Lbs.			
	1886.	1887.	1888.	1889.
Alabama	283,859	292,762	449,492	791,425
Tennessee	199,166	250,344	267,931	294,655
Virginia	156,250	175,715	197,396	251,356
West Virginia	98,618	82,311	95,259	117,900
Kentucky	54,844	41,907	56,790	42,518
Georgia	46,490	40,947	39,397	27,559
Maryland	30,502	37,427	17,606	33,847
Texas	3,250	4,383	6,587	4,544
North Carolina	2,200	3,640	2,400	2,898
Totals	875,179	929,436	1,132,858	1,566,702

Production of Cut and Wire Nails.—The official statistics published by the American Iron and Steel Association show the production of cut and wire nails in the United States in 1889 to have been as follows:—

States.	1889—Kegs of 100 Lbs.		
	Iron.	Steel.	Totals.
Pennsylvania	961,537	873,362	1,834,899
Ohio	50,045	1,496,883	1,546,928
West Virginia	3,463	976,883	980,346
Indiana	23,200	115,000	138,200
New Jersey	248,667	3,400	252,067
Illinois	...	204,438	204,438
Massachusetts	126,704	113,199	239,903
California	214,000	28,000	242,000
Virginia	144,998	50,000	194,998
Kentucky	...	165,000	165,000
Wisconsin	4,924	6,511	11,435
Alabama	...	...	...
Colorada	544	...	544
Tennessee	...	...	...
Total cut nails	1,778,082	4,032,676	5,810,758
Wire nails	...	...	2,200,000
Total nail production	...	...	8,010,758

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* *Iron Age*, vol. xlv. p. 812.

Consumption of Wire Rods.—Mr. J. M. Swank publishes the following statistics relating to the consumption of wire rods in the United States in 1889:—

Description.	Tons of 2000 Lbs.	
	1888.	1889.
Imports, iron and steel . . .	114,031	82,608
United States production, iron . .	14,571	14,460
„ „ steel . .	298,770	393,121
Totals . . .	427,372	490,189

Production of Iron Ore in New Jersey.—The following statistics appear in the Annual Report of the State Geological Survey of New Jersey for the year 1889:—

Years.	Tons.
1879	488,028
1880	745,000
1881	737,052
1882	932,762
1883	521,416
1884	393,710
1885	330,000
1886	500,501
1887	547,889
1888	447,738
1889	482,169

Coke Ovens in the Birmingham District.—The coke ovens in this district have increased in number within less than ten years from 216 to 4557 in operation and 340 building. Of these, 74 are of the Thomas patent, the out-turn from which is equal to about $2\frac{2}{3}$ of that of an ordinary beehive oven, such as those in general use on this field. The largest coke-producing company is the De Bardeleben at Bessemer, which possesses 920 ovens.*

The Production of Coal in Wyoming.—Dr. L. D. Ricketts, in the Annual Report of the Territorial Geologist to the Governor of Wyoming, 1890, states that the coal deposits of the new State are very extensive, the seams being occasionally from 15 to 20 feet in thickness. In 1888 there were twelve mines in Wyoming raising coal;

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* *Iron Age*, vol. xlvi. p. 456.

in 1890 the number had increased to twenty-four. The output of coal has been as follows:—

Years.	Tons.
1886	829,355
1887	1,170,318
1888	1,409,506
1889	1,412,958

XIII.—*COMPARATIVE TABLES.*

Coal and Iron Production of the World.—Mr. G. G. Chisholm * has instituted "An Examination of the Coal and Iron Production of the Principal Coal and Iron Producing Countries of the World, with reference to the English Coal Question."

With a view to this examination, a comparison is first made of the rates of increase in the amount of coal production in different countries. A table drawn up for this purpose shows that since 1860 the rate of expansion under this head has been less rapid in the United Kingdom than in several other countries, notably the United States and Germany. If the same average rates of expansion were continued indefinitely in the future for the United Kingdom, the United States, and Germany, respectively, as are found by calculation to have been maintained for these countries between the mean of the three years 1879–81 and the mean of the three years 1886–88, then the coal production of the United Kingdom would be overtaken by that of the United States in 1894, by that of Germany in 1928, by the aggregate coal and lignite production of Germany in 1919. A similar examination of the rate of growth of the production of iron shows that in this industry these two countries appear to be gaining still more rapidly upon the United Kingdom. This is important, as tending to bring about a diminution in the rate of increase in the demand for British coal. Hitherto the iron industry of the chief industrial countries has been greatly stimulated by the rapid extension of railways. An examination of railway statistics since 1840 shows that the new mileage required year by year all over the world has increased on the average at a somewhat high geometrical rate. The examination shows also, however, that this is brought about by the construction of railways on a large scale in different parts of the world successively.

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* Paper read before the Royal Statistical Society; *Industries*, vol. viii. p. 585.

Regions in which railways have long been laid show no such rapid increase in the amount of the new mileage. This leads to the conclusion that, sooner or later, a time will come when the rate of increase of the railway mileage of the world will be greatly reduced. That would probably involve a pretty severe check to the growth of the demand for iron, and indirectly that of the demand for coal.

With regard to the consumption of British coal, any conclusions that may be drawn from such data as are dealt with in this paper should be stated with great diffidence; but, so far as yet appears, there is no reason to anticipate at any time anything of the nature of a disaster or sudden catastrophe from the continued consumption of coal. The change of conditions will probably be a gradual one throughout. First, only the continuation of a process already begun may be expected, a gradual contraction in the rate of expansion of the coal production. That may pass insensibly into a stationary state of coal production, to be followed by a gradual decline. Such, remarks Professor Marshall, is the actually observed history of the working of individual coal-mines. It may be that the modification of the rate of increase or decrease of the amount of coal production will not always be so gradual as it is now; still, it is to be hoped that it may be gradual enough to allow of the habits of the people being adapted to the changing conditions. Nevertheless, the fact of the steady rate of increase in the aggregate number of the population of Great Britain, taken along with apparent signs of a declining rate of expansion in some of the chief industries of the country, is one that cannot be regarded with equanimity, and makes it urgently to be desired that the true state of the case should be carefully inquired into, and made as widely known as possible. With reference to the possibility of the influences adverse to the production of British coal being somewhat suddenly and strongly reinforced in the future, an account is given from Richthofen's "China," of certain great Chinese coalfields, the connection of which by rail with the great plain of China and the great seaports could not fail, according to Richthofen, "to bring about a revolution in the commerce and intercourse of the world."

The Coke Industry of the Continent.—According to statements published in *Glückauf*,* the production of coke on the continent of Europe was as follows in the year 1889, in the districts mentioned :—

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* Through *Stahl und Eisen*, vol. x. p. 742.

	Metric Tons.
Districts of the Ruhr and Lower Rhine	3,506,000
Wurm District	183,000
Saar District	700,000
Belgium	2,000,000
Northern France	790,000
Lower Silesia	252,000
Moravia (Austria)	200,000
Total . . .	7,631,000

The quantity of coal used in the manufacture of this coke probably approached 12 million tons.

Production of Coal and Iron.—The following table shows the world's production of coal and pig iron in metric tons: *—

Countries.	Years.	Coal.	Pig Iron.
Great Britain . . .	1889	176,916,724	8,245,336
United States . . .	1889	132,419,342	7,604,525
Germany	1889	81,960,000	4,387,504
France	1889	24,588,880	1,722,480
Belgium	1889	19,810,118	847,260
Austria and Hungary .	1888	23,500,000	761,606
Russia	1887	4,464,174	532,649
Austria	1889	2,664,172	...
Japan	1888	2,076,744	...
Sweden	1888	300,000	457,052
Spain	1888	1,203,119	232,000
Italy	1887	327,665	12,265
Other countries . .	1889	10,000,000	100,000
Totals . .		480,230,938	24,902,677

The Production of Iron Ore.—Professor Wedding † sums up the world's present output of iron ore as follows:—

Description.	Metric Tons.	Per Cent.
Iron ores rich in phosphorus	18,012,000	35·2
Phosphoric iron ores . . .	8,945,000	17·5
Iron ores poor in phosphorus	20,392,000	39·9
Iron ores rich in manganese	3,767,000	7·4
Totals	51,116,000	100·0

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* *The Engineering and Mining Journal*, vol. xlix. p. 680.

† *Stahl und Eisen*, vol. x. p. 651.

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